

Toxic Chemical Research Needs in the Lower Fraser River

Workshop Proceedings



Held at University of British Columbia, June 19, 1985.



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TOXIC CHEMICALS RESEARCH NEEDS
IN THE LOWER FRASER RIVER

WORKSHOP PROCEEDINGS
UNIVERSITY OF BRITISH COLUMBIA
JUNE 19, 1985

SPONSORED BY
REGIONAL TOXIC CHEMICALS COMMITTEE
ENVIRONMENT CANADA
PACIFIC AND YUKON REGION

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PREFACE

As the title of the Workshop implies, the intent of Environment Canada in sponsoring this Workshop was to focus on toxic chemicals research needs in the Fraser River estuary. Specifically, the Workshop was to address the following objectives:

1. to review the current status of knowledge regarding toxic substances in the Fraser River estuary;
2. to examine what additional information is required on toxics in order to more effectively manage water quality in the estuary; and
3. to recommend toxic chemicals research that will help improve the information required for managing toxic chemicals.

The Workshop provided a forum for key players in government, research institutes and universities to exchange ideas and information on current research findings relating to toxic chemicals in the Fraser River estuary.

In highlighting the key issues, the Workshop Proceedings should provide valuable guidance to managers and researchers in setting research priorities and in coordinating research programs. The Workshop also helped to forge a better understanding between the needs of managers and those involved in undertaking research on toxic chemicals. Many of the participants expressed a desire to see this type of dialogue continue on a regular basis.

The Proceedings of the Workshop should also be extremely valuable to those agencies participating in the Fraser River Estuary Management Program. One of the goals of the program is to develop and implement a water quality plan for the estuary. A top priority of this plan is to reduce overall and, in particular cases, eliminate the loading of persistent or cumulative toxic chemicals in the estuary. Many of the recommendations should be particularly useful in developing a water quality plan and a waste management activity program.

Dr. Ken Hall of the Westwater Research Centre, U.B.C., led off the Workshop with an overview of toxic chemicals in the estuary. Discussion groups followed, focussing on five major themes/sessions:

- I Identification of Toxic Chemicals and Determination of Sources
- II Hydrodynamics and Sediment Transport
- III Chemical Pathways
- IV Effects on Biota
- V Water Quality Objectives - Aquatic Environmental Quality Requirements

A wrap-up session highlighted the major discussion points in each of the sessions.

WORKSHOP ORGANIZATION

The Workshop was initiated by Dr. J.D. Wiebe, Chairman of the Pacific and Yukon Toxic Chemicals Coordinating Committee, who requested that a research agenda for toxic chemicals in the Fraser be developed. An Organizing Committee of the following members was established:

Fred Mah (Chairman)
Inland Waters Directorate

Rick Kussat
Environmental Protection Service

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Environmental Protection Service

Don Faulkner
Atmospheric Environment Service

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ACKNOWLEDGEMENTS

The Organizing Committee would like to extend their appreciation to the following individuals for their contributions to the Workshop:

- the Workshop facilitators and rapporteurs for leading and recording the discussions
- Bob Shepherd, EPS, for his assistance in writing up the Session I Proceedings
- Dick Boak, IWD, for his help in redrafting the figures in Ken Hall's paper
- Franca Corbie for typing the Proceedings

A REVIEW OF TOXIC SUBSTANCES IN THE FRASER RIVER ESTUARY

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INTRODUCTION

This review of toxic substances in the Fraser River estuary was presented to the workshop participants to give them a background on the current status of knowledge regarding trace metals and toxic organic contaminants in the lower Fraser. With this information base, the workshop participants could then develop a meaningful dialogue in their specific workshop sessions that would enable them to recommend research and better examine monitoring information requirements to effectively manage water quality in the lower Fraser River estuary.

This review is divided into two sections, namely trace metals and organic contaminants. It does not summarize all the information available, but rather places emphasis on the kinds of information that are available and some of the difficulties in using this information to develop water quality criteria and manage these toxic substances in the estuary. Each section deals with contaminants that are found in water, sediment and biota. Also, some of the factors that result in exchange between these three compartments are briefly discussed. No attempt was made to look at the sources of toxic contaminants to the estuary.

1.0 TRACE METALS

1.1 Trace Metals in Water

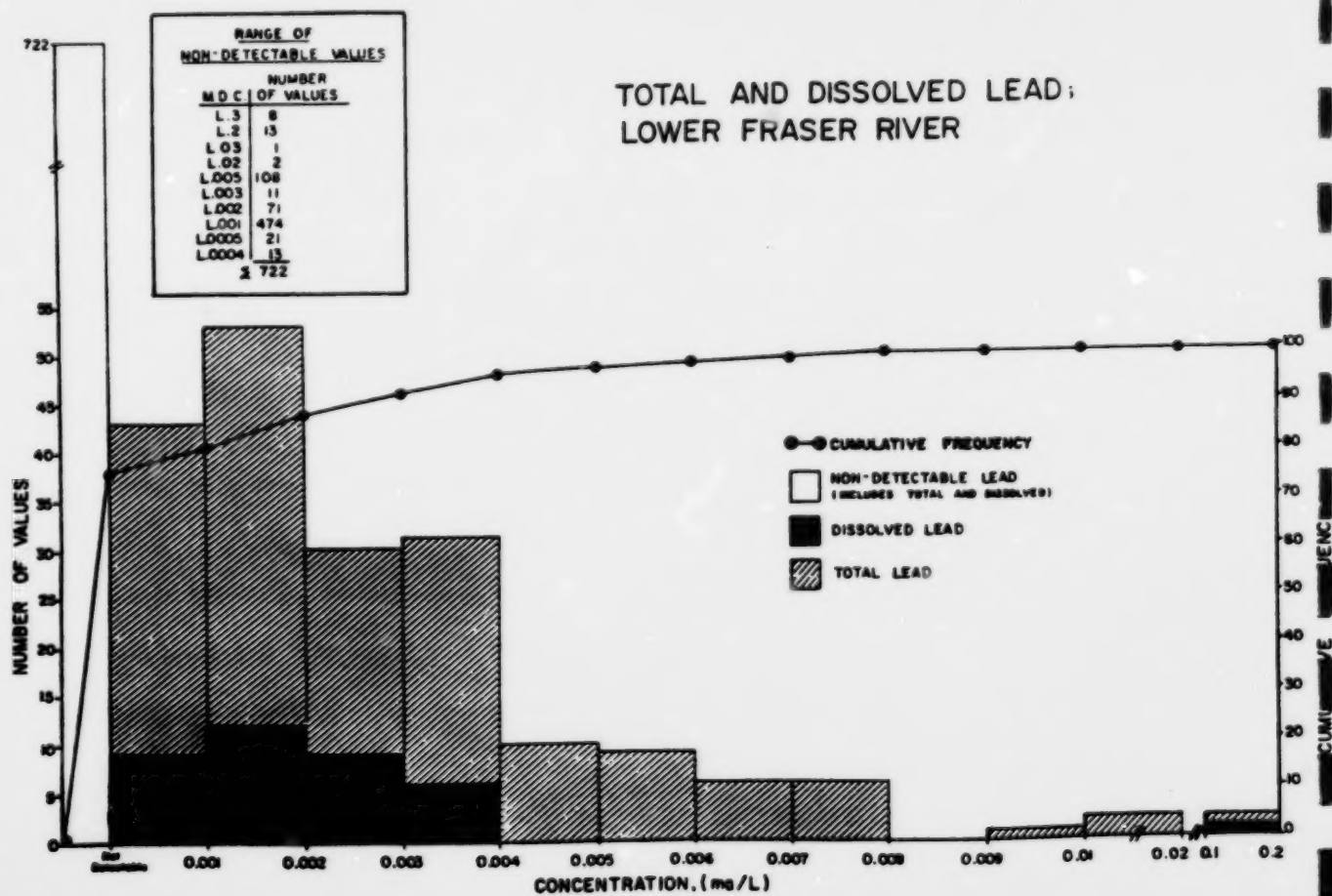
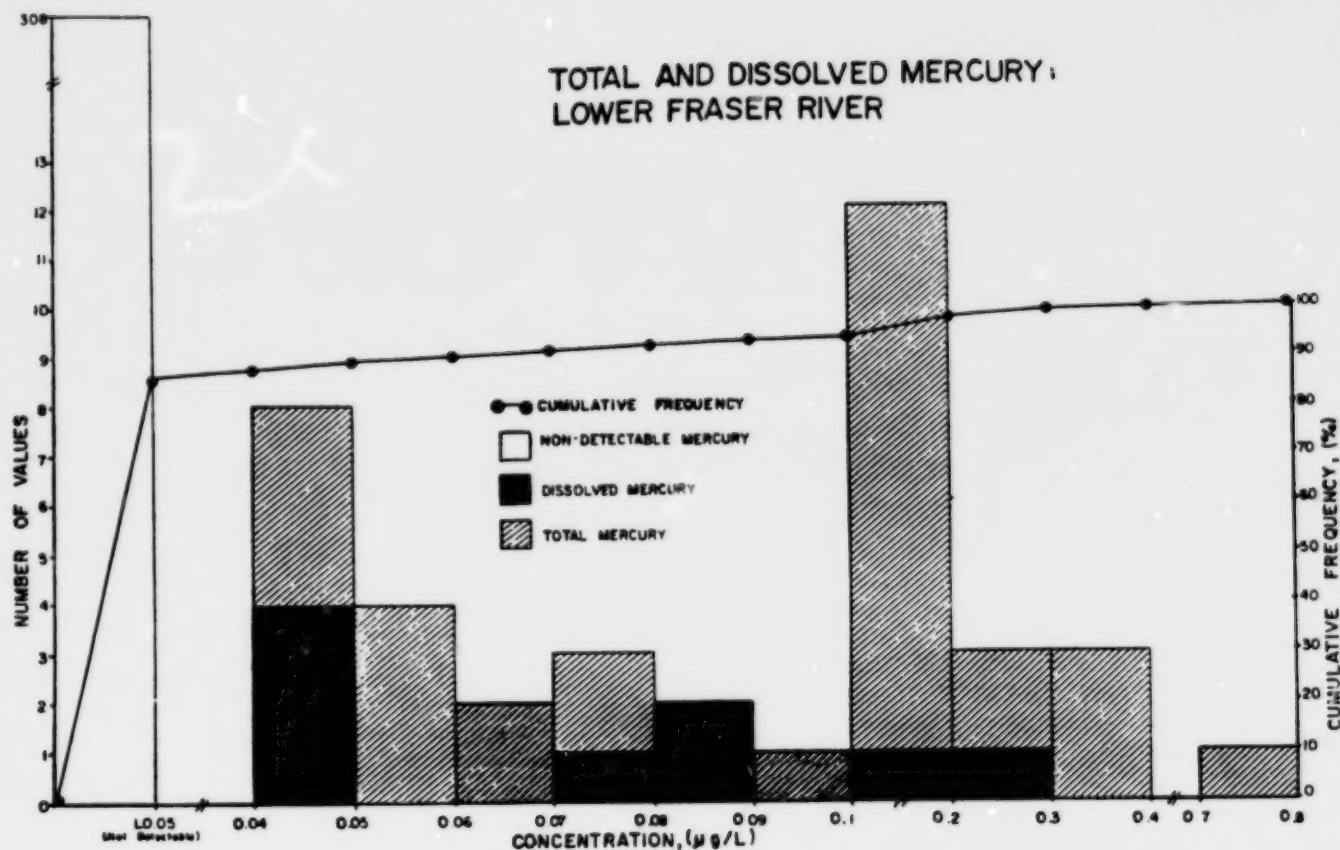
The information on trace metal levels in water from the lower Fraser from 1970-1978 has been summarized by Drinnan and Clark (1980). For each trace metal they show the number of samples that were analyzed and the concentration distribution of these analyses. Each metal is segregated into the dissolved and total metal for each concentration range. Figure 1 illustrates these data for mercury and lead. It is readily evident from the data that a wide range of concentrations have been measured for each element. Many of the measurements were less than the detection level. Since a wide variety of techniques were used for the data set, Drinnan and Clark (1980) provide a breakdown of the detection levels and the number of values that were below the detection level for the technique that was used (see the tabulated example for lead in Figure 1).

Drinnan and Clark (1980) also provide some information on the spatial and temporal distribution of trace metals in water. Figure 2 illustrates the range, median, and percentile values for zinc in different reaches of the river for Kanaka Creek to the banks in the Strait of Georgia. If one looks at all these data it is difficult to determine any significant difference in many reaches of the river. This is true for most metals in their data review. For the zinc data one could qualitatively state that there appears to be a higher average concentration of zinc in the main arm of the river than is found in the main stem, but the range of values shows considerable overlap. From these data one can readily see the difficulty in establishing meaningful water quality criteria for trace metals even though many analyses have been made.

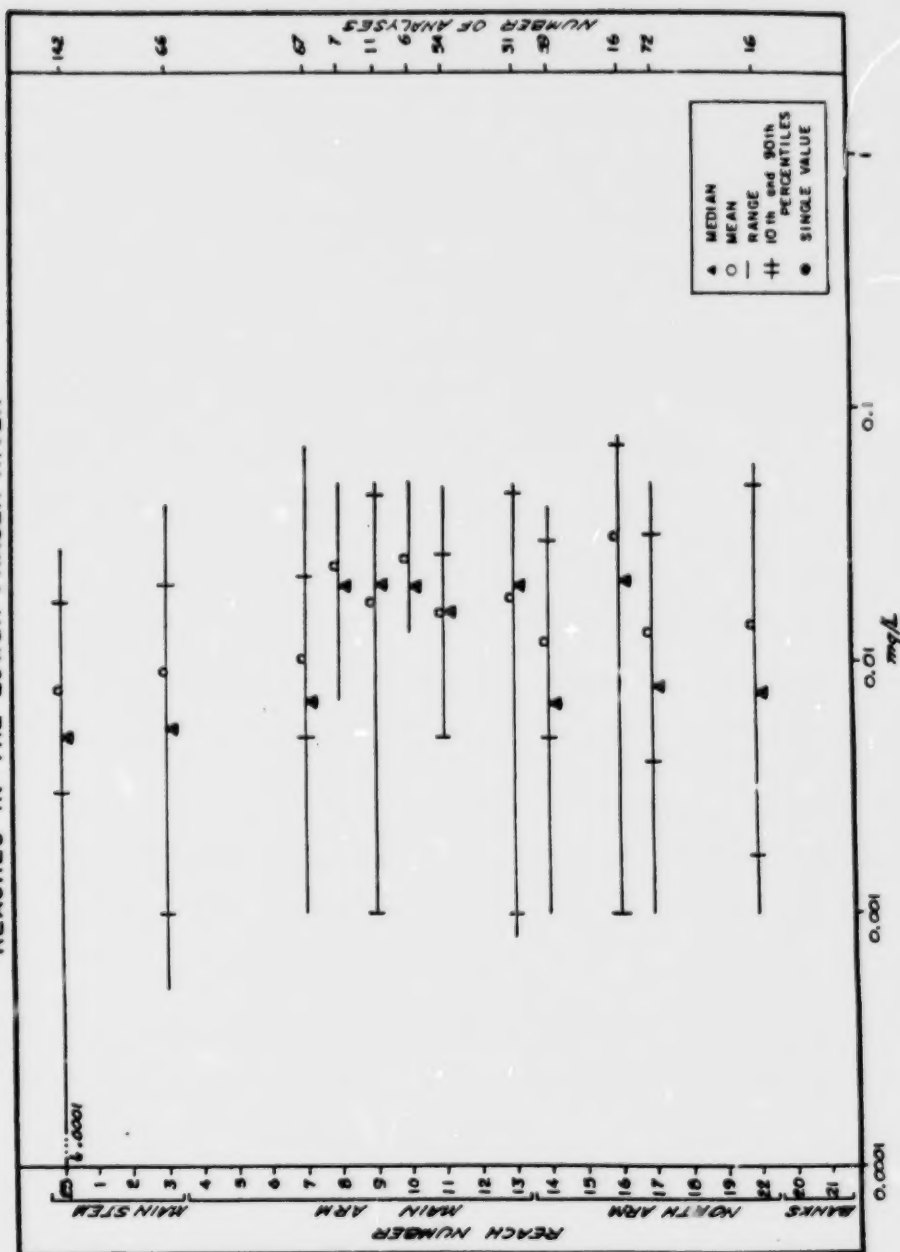
The concentrations of trace metals in the sloughs, harbours and other backwater areas may provide an assessment of various land use activities and discharges in contributing trace metals to the lower Fraser. Metal levels in these backwater areas may serve as early indicators of emerging pollution problems that can be controlled before they become severe enough to show up in the main river channels. Some selected trace metal data from the slough and sidechannel habitats near Ladner, B.C., adjacent to the Main Arm of the river, are summarized in Table 1. Copper and lead concentrations appear to be similar to average concentrations found in the open water channels (see Hall et al., 1974), but zinc and mercury concentrations are higher than most values found in the open channels. There was also considerable seasonal variation in mercury concentrations in an upper slough station (Figure 6) with levels below the detection level ($<0.05 \text{ ug/l}$) during the freshet increasing to 0.7 ug/l during low flow in January.

The trace metal chemistry in water can be further complicated by exchange reactions that take place with suspended sediments. Grieve and Fletcher (1977) investigated the concentration and speciation of zinc along a transect down the Main Arm of the Fraser. They found an increase in the suspended sediment associated zinc and dissolved zinc on entering the brackish water that could not be explained by mixing or simple sorption-desorption reactions. Their research suggested that some internal recycling of zinc was increasing the residence time in the estuary relative to that in the freshwater. There was a five-fold increase in leachable zinc associated with the suspended solids in the brackish water when compared to the freshwater. Thus, the chemical environment can influence the form and availability of many trace metals and could have implications in establishing water quality criteria to adequately protect aquatic organisms.

Figure 1



SUMMARY OF TOTAL ZINC DATA FOR THE INDIVIDUAL REACHES IN THE LOWER FRASER RIVER



A lot of the variability in the data summaries presented by Drinnan and Clark are probably attributable to the wide variety of techniques that were used to generate the data set and what each technique assumes to be a dissolved or total metal analysis. If a single study is selected to look at the spatial trace metal distribution in the lower Fraser, a pattern of contamination becomes more evident. Figure 3 shows the range of values for mercury, lead and zinc in different reaches of the river for a series of samples collected between February and May 1973. This figure and the complete data set (see Hall et al., 1974) shows that there were sporadic higher levels of these three trace metals found in the lower reaches of the river during this study, although the median values do not show large spatial differences and mean values tend to be unfairly biased towards the few high levels that were measured. With this kind of data there are still difficulties in selecting a valid statistical parameter to set adequate water quality criteria and consider the sporadic nature of high levels that occur.

There are seasonal changes in some of the trace metals in the lower Fraser River. Plots of the monthly means for total metals often show peaks that are coincident with the high flow period between May and August when suspended sediment concentrations are high (see Figure 4 for iron and copper selected from Drinnan and Clark, 1980). Considerable variation can even occur at one station over a tidal cycle (Figure 5). The suspended sediments near the bottom during the ebb tide contained very high concentrations of extractable copper, iron and zinc when compared to concentrations during other periods of the tidal cycle. This natural spatial and temporal variability creates problems in establishing a water quality monitoring program to follow compliance with any criteria that are established.

Figure 3

Trace Metals in the Lower Fraser River

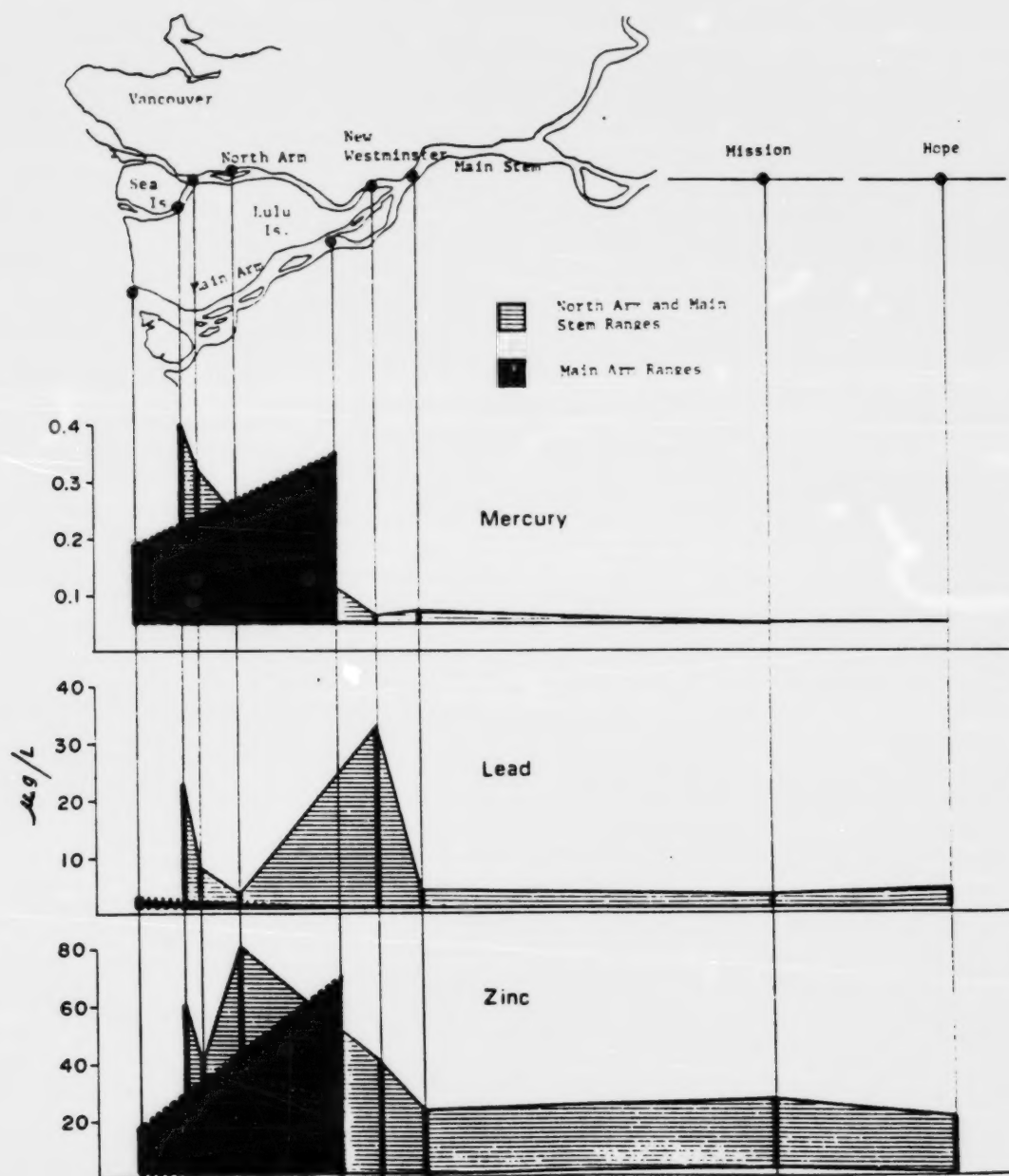
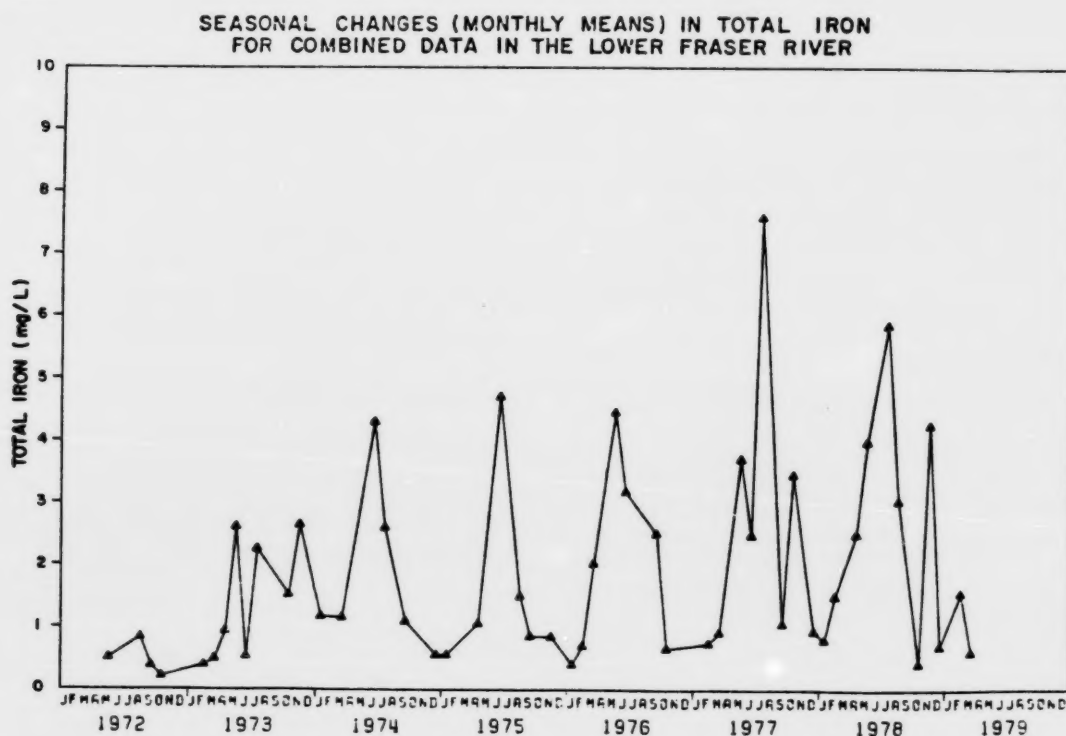
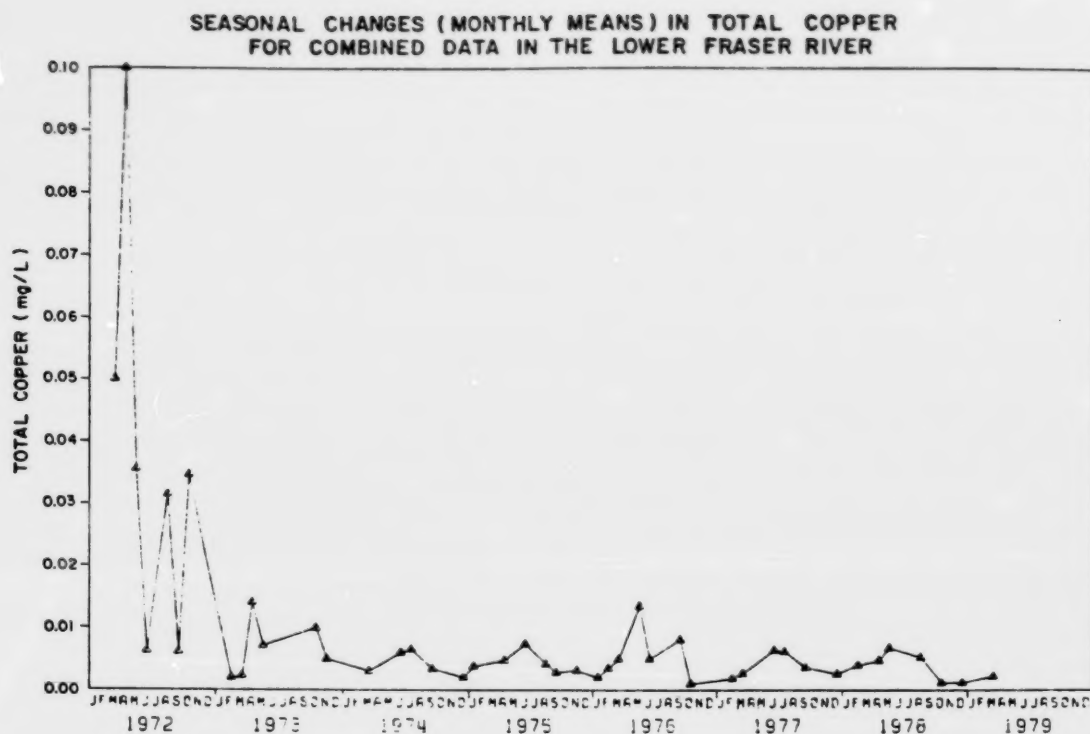


Figure 4



CHANGES IN CONCENTRATIONS OF EXTRACTABLE METALS, SUSPENDED SOLIDS AND VELOCITY, DURING A TIDAL CYCLE NEAR STEVESTON ISLAND (R11), OCTOBER, 1977.

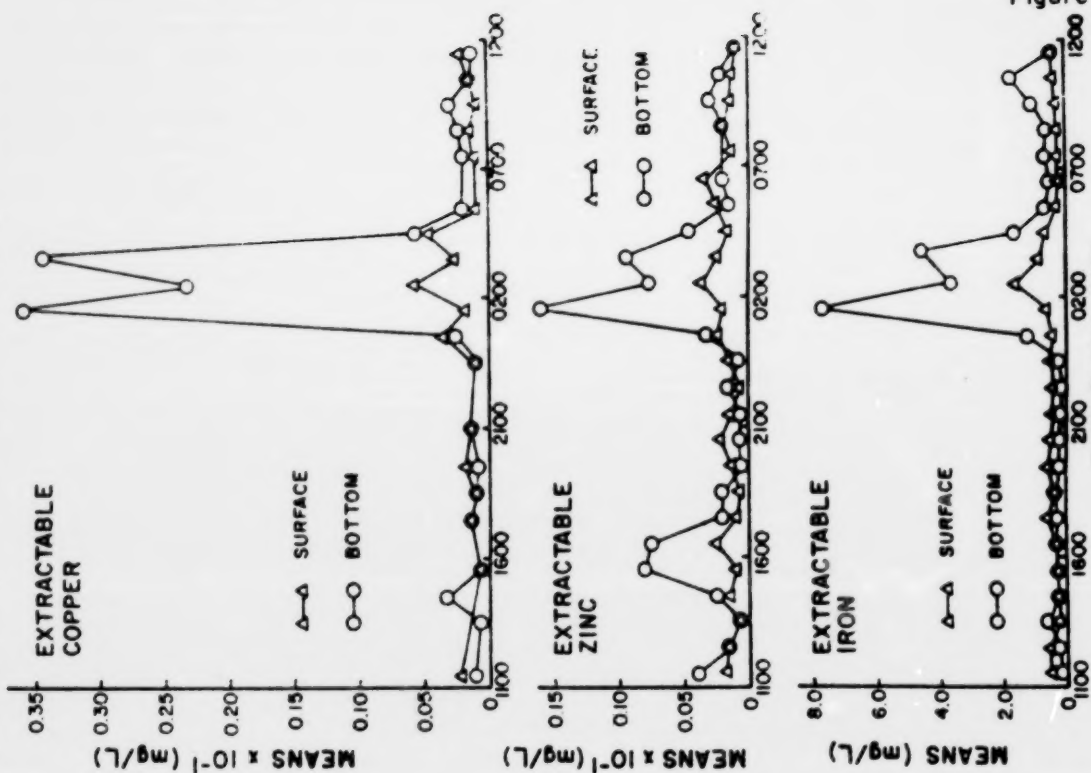
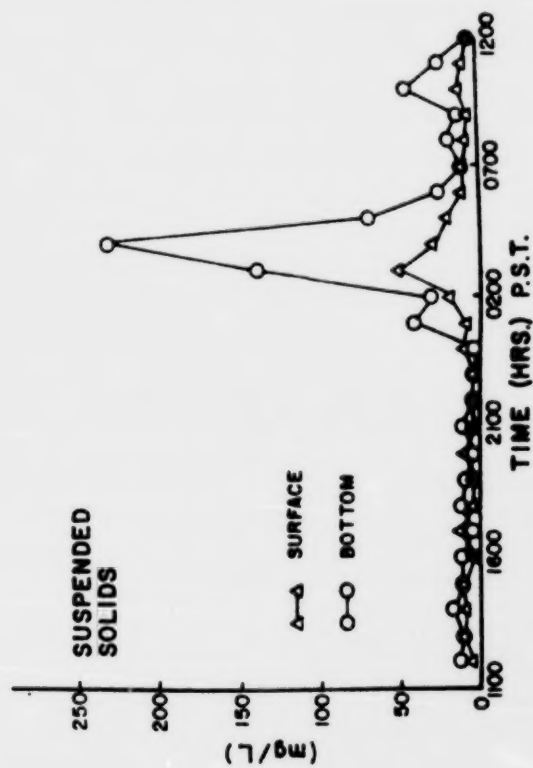
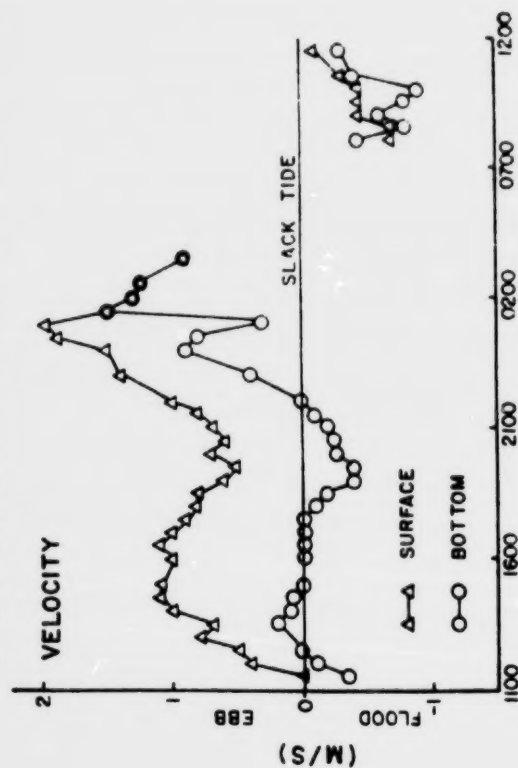


Figure 5

Figure 6

Seasonal Variation in Mercury in Ladner Slough
(Station A)

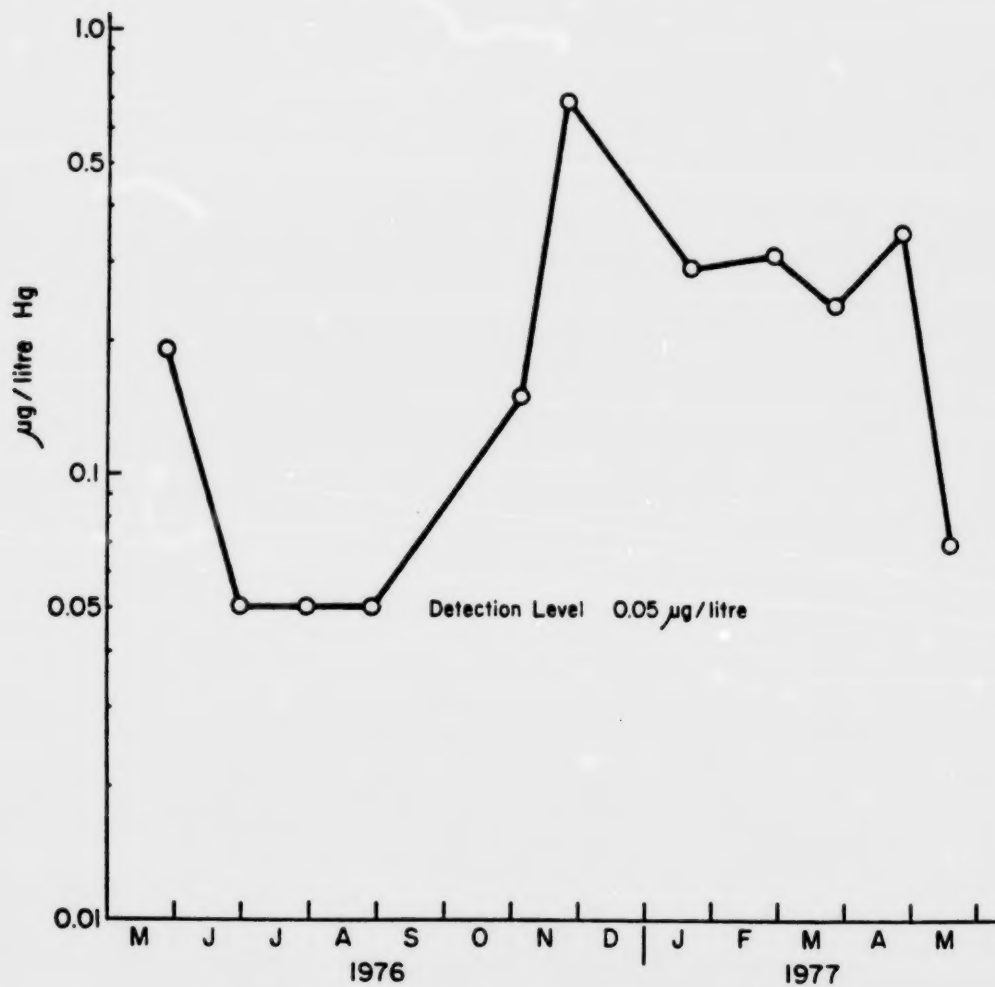


Table 1. Trace Metals in Water from Slough/Habitat

Area		Copper	Lead	Zinc	Mercury
Ladner Slough	A	10	1	160	0.19
	B	10	1	115	0.20
	C	10	1	100	0.19
Williamson Slough		10	1	205	0.23
Development Slough		17.5	< 1	125	0.29

Hall (unpublished data)

Station C at mouth of Slough, Station B at middle of Slough and
Station A at upper end of Slough

Table 2. Trace Metals in Sediments on Fraser Estuary⁽¹⁾

Area	Copper	Lead	Zinc
Lower Mainstem	28-35	6-10	63-75
North Arm	22-38	23-40	78-90
Main Arm	17-20	1-5	41-50
Backwater Areas	26-118	6-370	41-470
Tidal Flats (Iona Outfall)	33-331	27-236	81-303

⁽¹⁾Stancil (1980). $\mu\text{g.g}^{-1}$ dry wt.

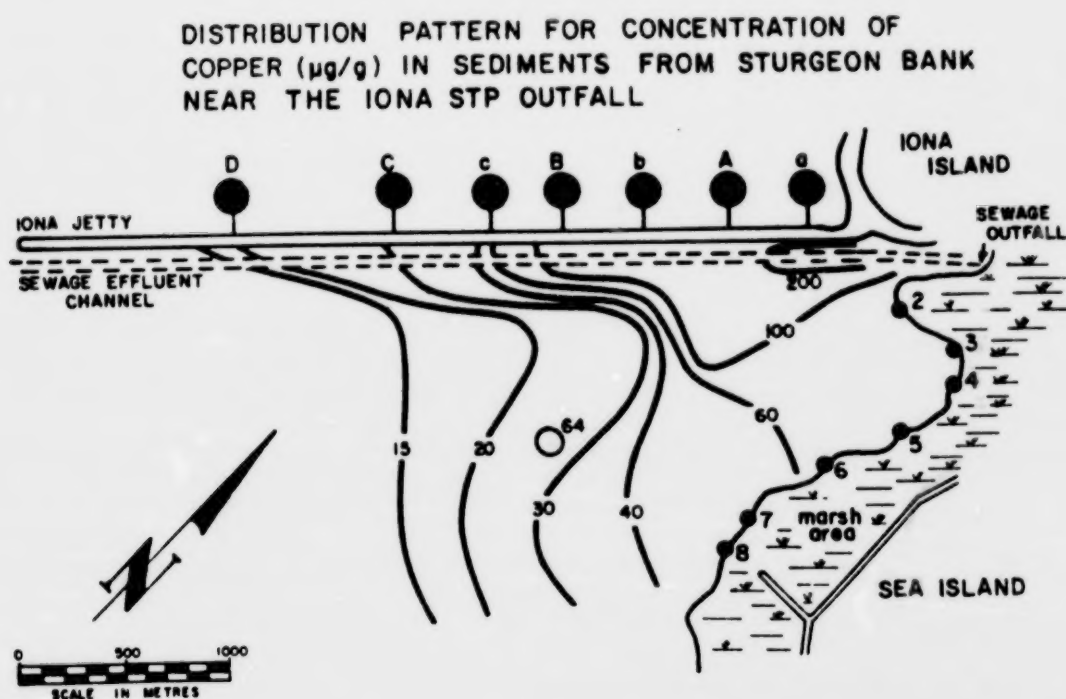
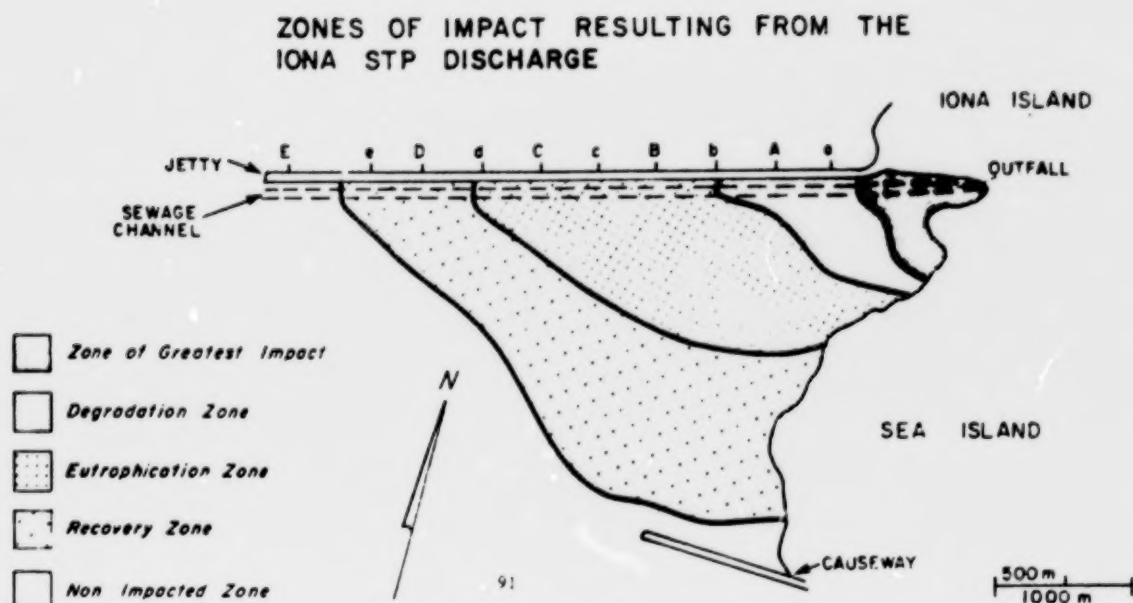
1.2 Trace Metals in Sediments

Most trace metals are fairly insoluble in water and tend to precipitate or adsorb to particulate material. Sedimentation of these materials can provide a historical record of pollution in an area and help to document sources of pollution. Unfortunately, the dynamic transport of sediments in the Fraser, especially during freshet, make the documentation of pollution through sediment analysis difficult.

A selection of trace metal levels in sediments from several areas of the lower Fraser is presented in Table 2. The range of trace metal values indicates that there are higher levels of some elements, such as lead and zinc, in sediments of the North Arm when compared to the Main Arm and Main Stem of the river. The backwater slough areas and areas where there are large point sources of pollution, such as the Iona Island sewage treatment plant outfall, also show higher concentrations of trace metals associated with the sediments. The extent of sediment contamination on Sturgeon Banks as a result of the Iona Island STP outfall has been well characterized by B.C. Research investigations (see Figure 7 which shows the general area of degradation and illustrates the contours of copper contamination associated with the sewage outfall). The levels of trace metal contamination adjacent to Iona are highly correlated with the organic deposits from the sewage treatment plant (Bindra and Hall, 1977).

As long as the toxic trace metals remain immobile in sediments there is probably little cause for concern. However, accumulation in benthic invertebrates and/or release into the water column can create problems. The factors which affect these exchange reactions are complex and will not be discussed here. It is very evident that the levels of metal released or

Figure 7



accumulated are not often related to the total metal in the sediment, but the form of the metal. For example, in studies conducted in Ladner Slough, it was found that there was a gradual increase in concentration of most metals with distance into the slough (Table 3). However, as illustrated for copper in Table 4, the oligochaetes at some of the outer stations contained higher concentrations of copper which appeared to be more directly related to the copper that was easily exchangeable and/or acid extractable (Bindra and Hall, 1977).

Thus, it will be very difficult to establish safe sediment trace metal criteria unless detailed information is considered on the geochemistry of the metals associated with the sediments and factors which cause exchange reactions.

1.3 Trace Metals in Organisms

Information on trace metals found in aquatic organisms from the Fraser River can be found in several publications (Bawden et al., 1973; Northcote et al., 1975; Stancil, 1980; and Singleton, 1983). Mercury has been selected to illustrate the levels of metal contamination found in aquatic organisms from the Fraser estuary.

The concentrations of mercury found in crabs as a function of size is shown in Figure 8 (Bawden et al., 1973). There were higher mercury concentrations in the larger crabs collected from Sturgeon Banks when compared to Roberts Bank or other estuaries such as Kitimat and Cowichan Bay. These high mercury levels were above acceptable levels for human consumption (0.5 mg/kg wet wt.) and were directly attributable to discharges from the Iona Island STP.

Table 3. Total Trace Metals in Sediments¹ (Surface)

Station	Cu	Fe (%)	Mn	Ni	Pb	Zn	Org. Matter (%)
Ladner Slough							
A	76	4.37	593	96	32	140	12.5
B	60	3.92	616	72	28	112	4.3
C	53	3.83	654	70	17	92	5.6
Williamson Slough	28.5	3.13	471	91	13	57	< 1
Main Arm Fraser	19	1.27	333	34	4	33	< 1

Average Values in mg/kg dry weight, Fe as percent

Station C at mouth of Slough, Station B at middle of Slough and
Station A at upper end of Slough

Table 4. Copper Distribution in Sediments & Benthos
in Ladner Slough

Station	Geochemical Fractions						Organisms (oligochaetes)
	IW	EP	ERP	OSP	EAEP	Residue	
A	< .04	< .01	< .65	74	3.8	21.4	28
B	< .04	1.2	< .56	15.6	50.2	32.5	40
C	< .02	< .02	< .64	22.3	48.6	28.5	34

Geochemical fractions expressed as a percentage, organisms as ppm

IW = interstitial water
 EP = exchangeable phase
 ERP = easily reducible phase
 OSP = organic sulphur bound phase
 EAEP = easily acid extractable phase

Table 5. Trace Metals in Algae (Periphyton)

Area	Copper	Lead	Zinc
New Westminster	46	51	153
Oak Street	50	55	185
Steveston	46	24	94
Iona Jetty (N)	10	< 4	39
Iona Jetty (S)	18	<10	122
Still Creek	349	881	1300

Stancil (1980); $\mu\text{g.g}^{-1}$ dry wt.

Figure 8

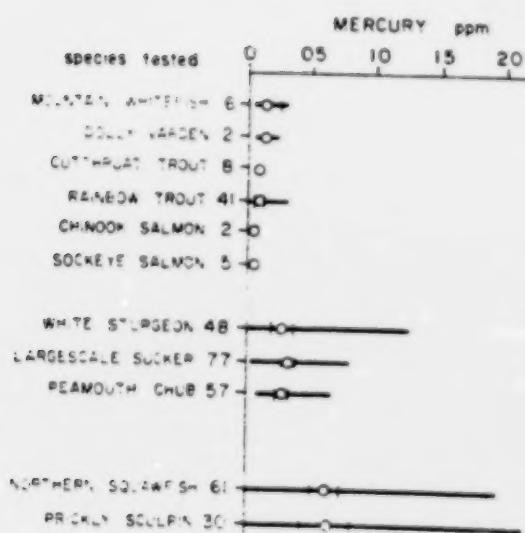
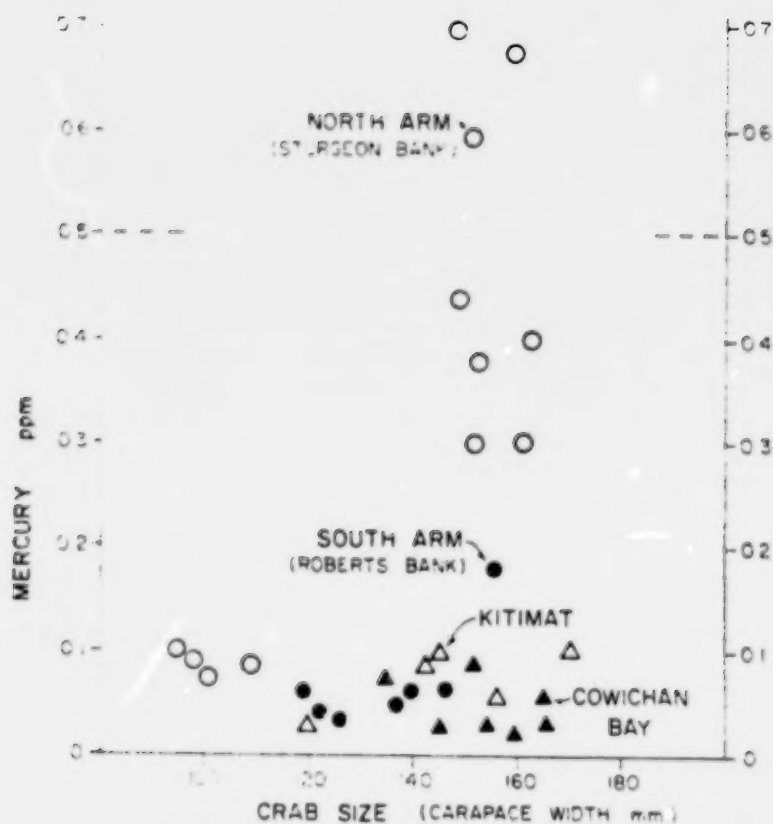
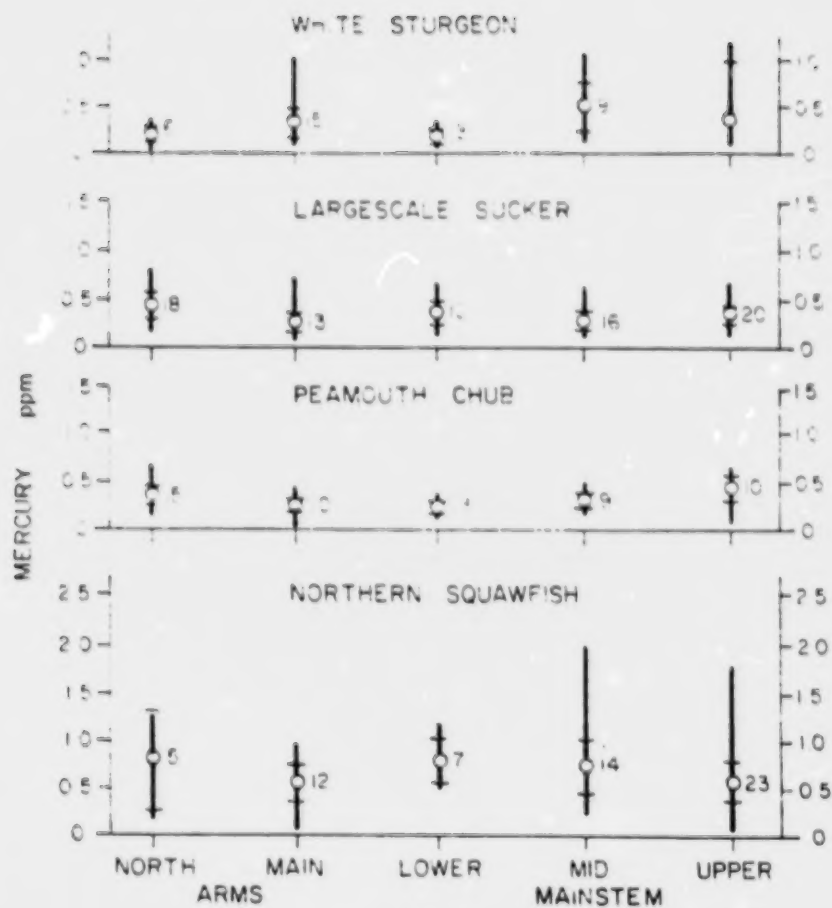


Figure 9

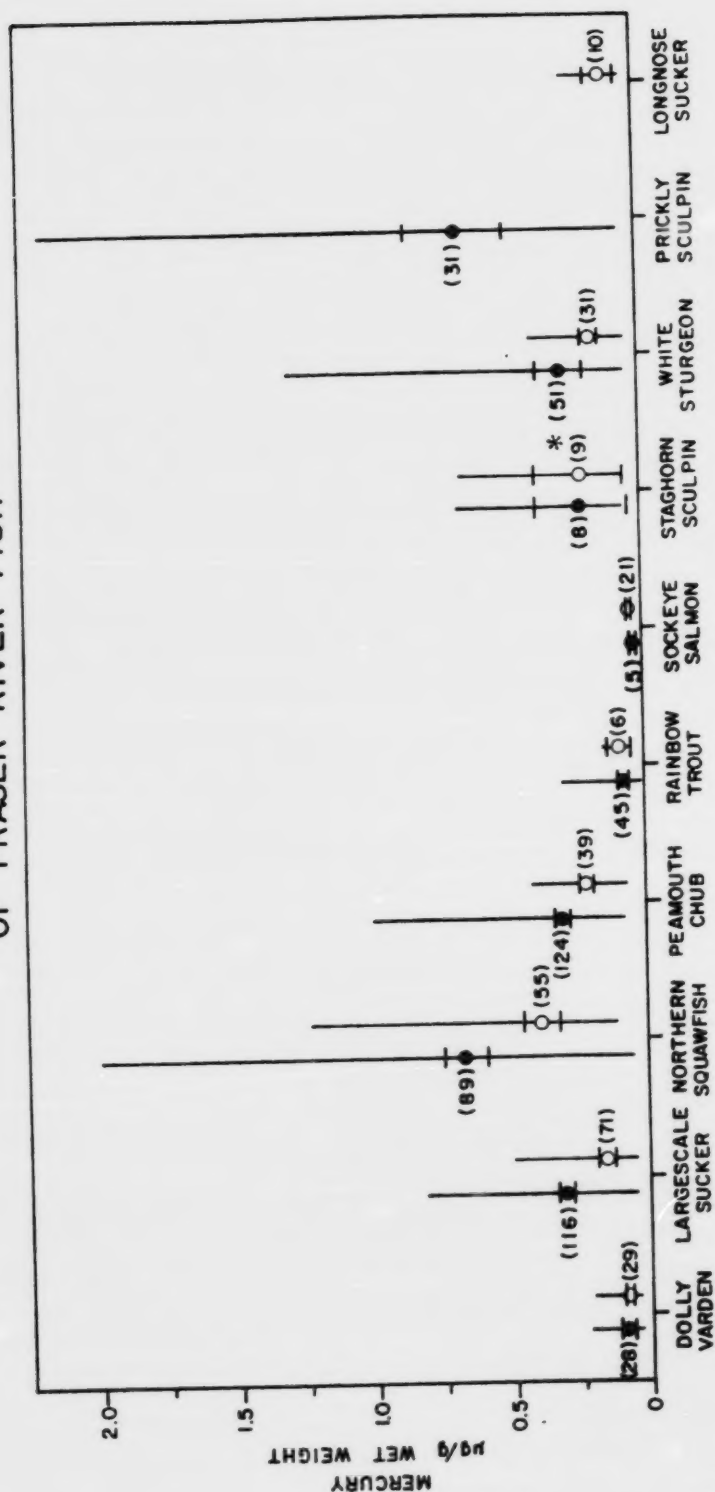
Mercury levels found in different species of fish collected from the Fraser River are summarized in Figure 9. The average mercury concentrations were below the acceptable levels for all species except northern squawfish and prickly sculpin. Some of the higher values for mercury in white sturgeon, large-scale sucker, and peamouth chub exceeded the acceptable levels of 0.5 mg/kg. There was no apparent difference in mercury concentrations in fish collected from different reaches of the river (Figure 10). Therefore, it is difficult to blame mercury contamination on our urban activities in the lower reaches of the river.

Concern over mercury pollution, since the well-publicized 'Minimata' disaster in Japan, has resulted in tighter regulations to control mercury in discharges. Figure 11 compares mercury concentrations in fish tissue collected in 1980 (Singleton, 1983) with earlier results from 1972-73 (Northcote et al., 1975). For some species, notably large-scale sucker, northern squawfish, peamouth chub and white sturgeon, there appears to have been a decrease in the average mercury level in some fish tissue. Since the number of individuals analyzed in both studies was quite high (30-124), these average changes appear to be real. However, it would be necessary to compare the analytical techniques and size distribution of the species analyzed to substantiate these changes. Segregation of these two mercury studies into different reaches of the river still shows a decrease in mercury levels for comparable reaches as is illustrated for northern squawfish in Figure 12. Mercury levels in squawfish collected above Hope, B.C., also appear to be much lower than was found in fish collected from reaches that run through the lower Fraser valley.

Figure 10



MERCURY CONCENTRATIONS IN THE MUSCLE TISSUE OF FRASER RIVER FISH



For explanation of symbols, see Figure 3-a

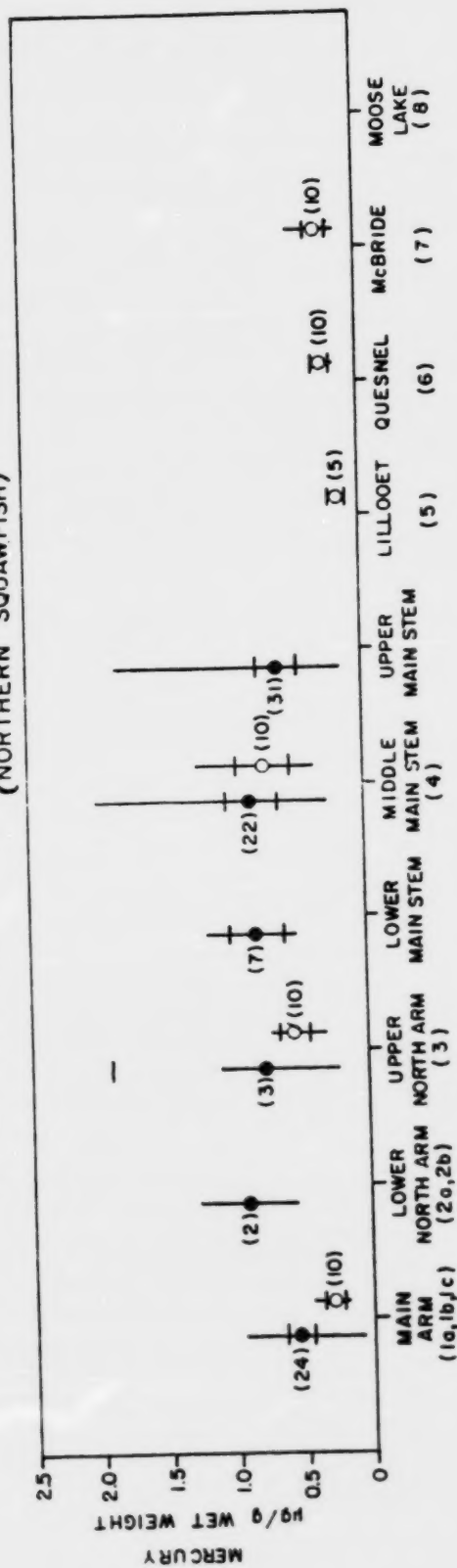
* = Composited samples

O = 1980 fish.

● = 1972-73 Westwater fish.

Figure 11

MERCURY CONCENTRATIONS IN THE MUSCLE TISSUE OF FISH
FROM DESIGNATED REACHES OF THE FRASER RIVER
(NORTHERN SQUAWFISH)



Other aquatic organisms, in addition to those of commercial value such as fish and crabs, are often used to evaluate trace metal contamination in the aquatic environment due to their high adsorptive potential and/or close association with sediments. Table 5 shows the distribution of copper, lead and zinc found in periphytic algae collected from different areas of the lower Fraser (Stancil, 1980). Lead and zinc concentrations appear to be higher in algae collected at New Westminster and Oak Street than was found in the Main Arm at Steveston. The concentrations of copper and lead associated with algae collected in the marine environment, along the Iona jetty, are low when compared to the freshwater environment which may reflect the solubility or availability of these metals under the saline water conditions. The concentrations of Cu, Pb and Zn are higher in algae from the south side of the Iona jetty when compared to the north side as a result of the sewage treatment plant discharge on the south side of the jetty. However, these differences appear quite small compared to the difference in trace metal contamination in sediments from these two areas. The freshwater periphyton collected from highly urbanized Still Creek, which receives stormwater drainage, was highly contaminated with trace metals when compared to the lower Fraser stations.

Selected trace metal levels in aquatic invertebrates are illustrated for amphipods (Table 6) and oligochaetes (Table 7). The levels of Cu, Hg, Pb and Zn are considerably higher in amphipods collected from a backwater area such as Ladner Reach when compared to more open areas such as the North Arm at Oak Street. Oligochaetes collected from the Brunette River, which runs through the highly urbanized municipality of Burnaby and receives

Table 6. Trace Metals in Amphipods (Anisogammaris)

Area	Copper	Lead	Zinc	Mercury
Oak Street	50	18	76	0.06
Westham Is.	85	18	75	0.05
Ladner Reach	104	45	181	1.15

Stancil (1980) $\mu\text{g.g}^{-1}$ dry wt.

Table 7. Trace Metals in Oligochaetes

Area	Copper	Lead	Zinc
New Westminster	20	39	122
Oak St.	15	12	83
Ladner Slough	27	5	67
Brunette R. (urban)	119	486	438
Salmon R. (agric.)	33	19	289

Stancil (1980) $\mu\text{g.g}^{-1}$ dry wt.

considerable stormwater drainage, contained much higher levels of Cu, Pb and Zn than was found in organisms from the Fraser or the Salmon River (an agricultural drainage).

The use of attached algae or benthic invertebrates, which do not move large distances during their life cycle, should be more useful to monitor trace metal pollution sources than fish which are highly mobile. However, the use of any aquatic organism as a bioassay organism will necessitate some understanding of the factors that regulate the availability of the pollutant to the organism if it is to serve as a useful biological monitor.

2.0 ORGANIC CONTAMINANTS

The US-EPA has established a list of priority pollutants which includes 114 organic compounds. For analytical purposes, these compounds are divided into an acidic fraction and a base-neutral fraction. The acidic fraction contains phenols, nitrophenols and chlorinated phenols, while the base-neutral fraction includes polycyclic aromatic hydrocarbons (PAHs), halogenated hydrocarbons such as pesticides and polychlorinated biphenyls (PCBs), phthalate esters and aromatic solvents such as benzene and toluene. This list often serves as an initial focus to survey the extent of organic contamination of an aquatic environment. Other compounds may be important contaminants due to specific industrial activity. For example, tetrachlorophenol is not on EPA's list of priority pollutants, but it is an important contaminant in the Fraser estuary due to the widespread use of chlorophenols as wood preservatives.

2.1 Organic Contaminants in Water

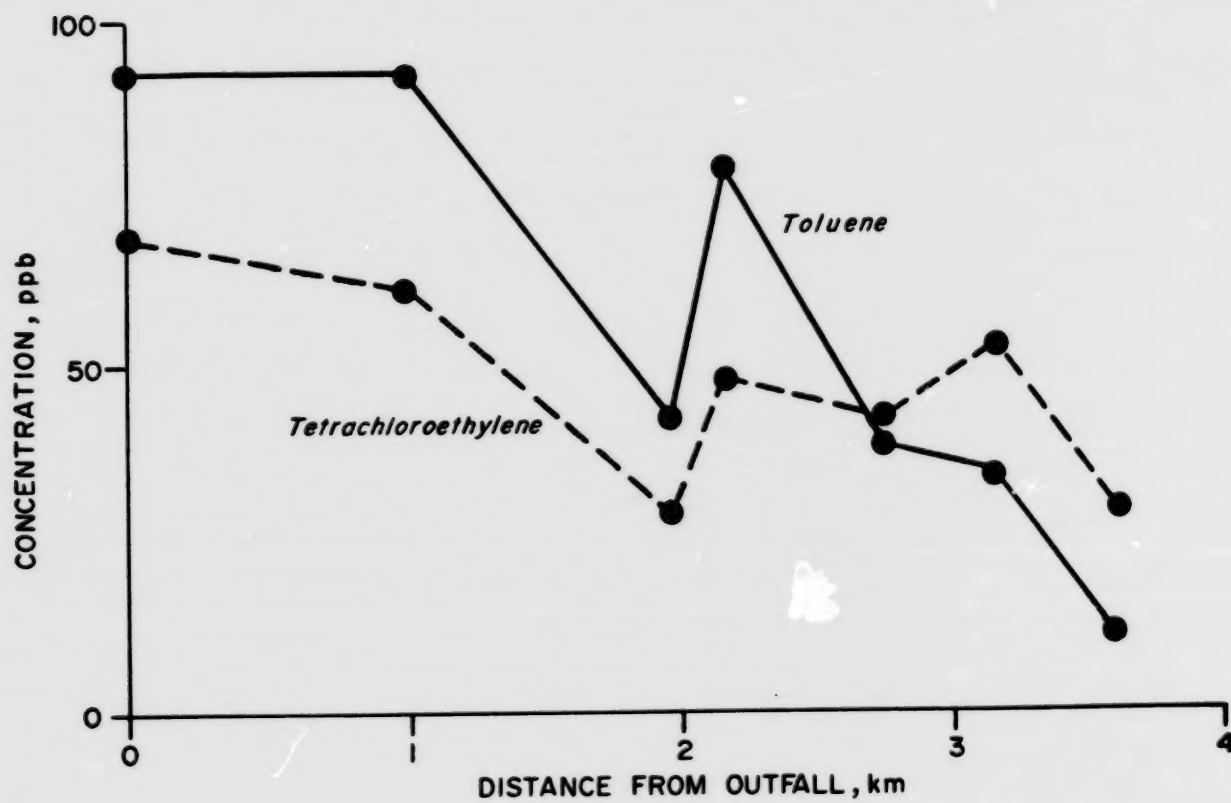
Very little information is available on the variety of organic contaminants in water from the lower Fraser River system. This is attributable to the difficulty of analysis due to the low detection level required and the expensive nature of most analyses which require gas chromatography/mass spectroscopy (GC/MS) to separate and identify compounds in trace quantities.

Drinnan and Clark (1980) summarized the data available for phenolic contaminants between 1970-1978. Over 300 samples were analyzed which had a median concentration of < 0.01 mg/l with only 29 values greater than 0.02 mg/l. Samples collected near Tilbury Island (downstream of Dow Chemical) and Annacis Island (adjacent to the STP) contained concentrations of phenols which were usually higher than other areas of the main stem Fraser.

Hall et al. (1974) collected 70 water samples from the lower Fraser and tributaries between March and May of 1973 and analyzed them for 15 chlorinated hydrocarbon pesticides. All samples were less than the detection level except for some lindane (0.03 ug/l) found in a water sample from Deer Creek in Burnaby.

Birtwell et al. (1983) identified 15 organic contaminants in receiving waters of the Iona Island STP on Sturgeon Banks using GC/MS analysis. The contaminants included halogenated volatile compounds such as chloroform and tetrachloroethylene, aromatic solvents such as benzene and toluene, and acidic components such as benzoic acid and phenylacetic acid. There was a gradual decrease in the concentrations of toluene and tetrachloroethylene with distance from the STP outfall (see Figure 13).

Figure 13



Recent concern over contaminants from wood preservatives used by mills adjacent to the Fraser River has initiated studies to determine the levels of chlorinated phenols in the water. Carey (1985) collected a series of water samples in September 1984 and identified 2,4,6-dichlorophenol (DCP), 2,3,4,6 - tetrachlorophenol (TTCP), and pentachlorophenol (PCP) as the major chlorinated phenol contaminants. The highest concentrations (56-91 ng/l) were found in the Mitchell Island channel of the North Arm, which happens to be close to several industries that use chlorophenol wood preservatives (Figure 14). More detailed studies over a tidal cycle have indicated that the discharge of the chlorophenols is very sporadic and concentrations can reach several ug/l (see Figure 15, Jacob and Hall, 1985). A series of 8-hour composite samples taken over a period of one week also showed incidences of sporadic discharge which appeared to be repeated in the early morning hours and could be a deliberate attempt to illegally discharge waste material (Figure 16; Jacob, 1985).

It would be very difficult to set up a water quality monitoring program to adequately manage trace organic contaminants such as chlorinated phenols due to the sporadic nature of the high concentrations that occur. Such a program would involve extensive analysis and would be very expensive. Yet it is important to document and control these sporadic discharges since aquatic organisms which can bioconcentrate organic pollutants will tend to concentrate the pollutants in their tissue in proportion to the levels in their environment. Perhaps aquatic organisms could be used as instream biological monitors to integrate the average levels of pollutants that they are in contact with over a given period of time (Jacob and Hall, 1985).

Figure 14

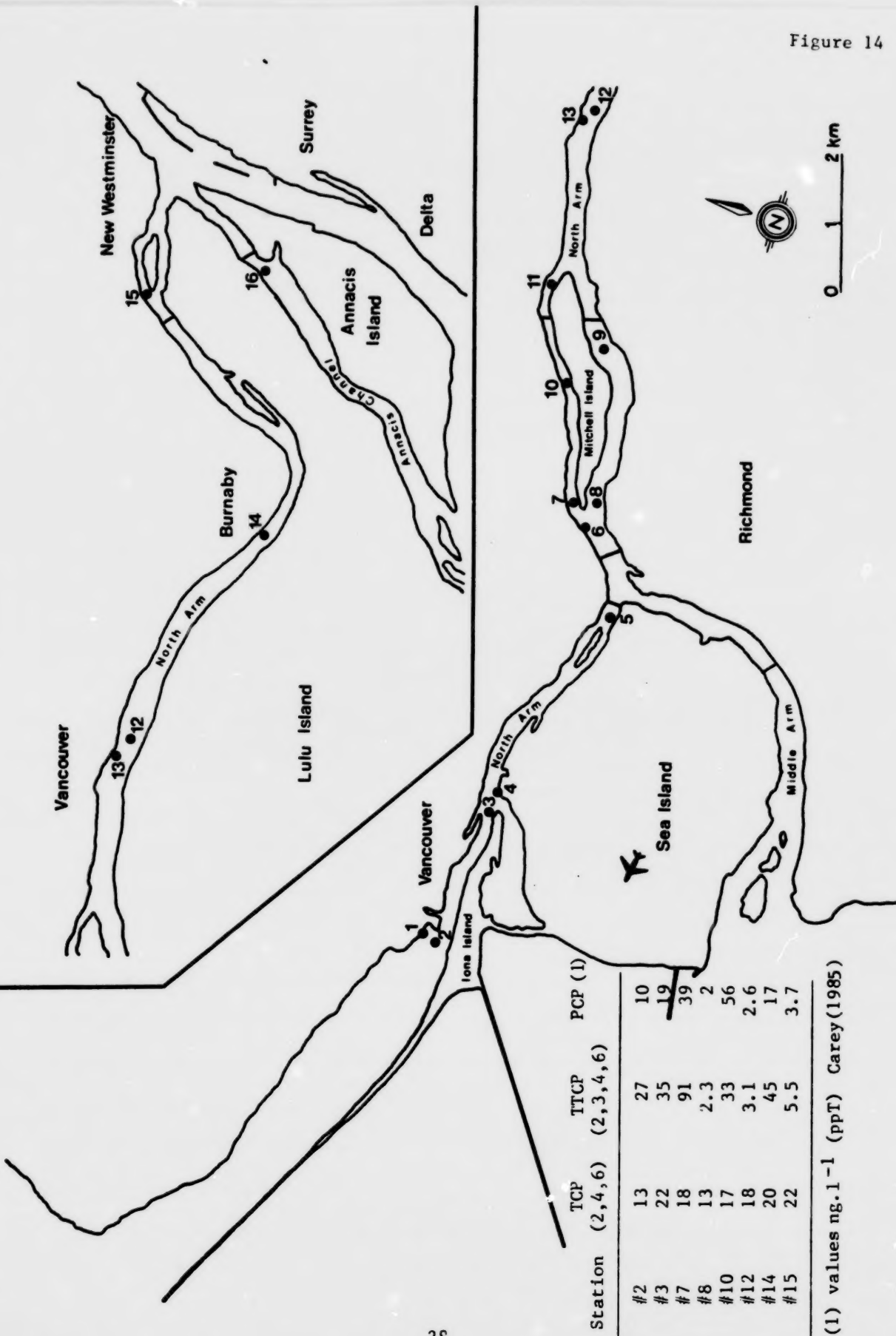


Figure 15

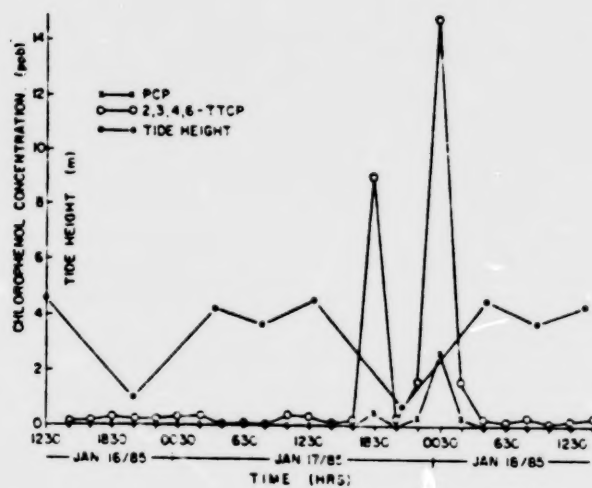
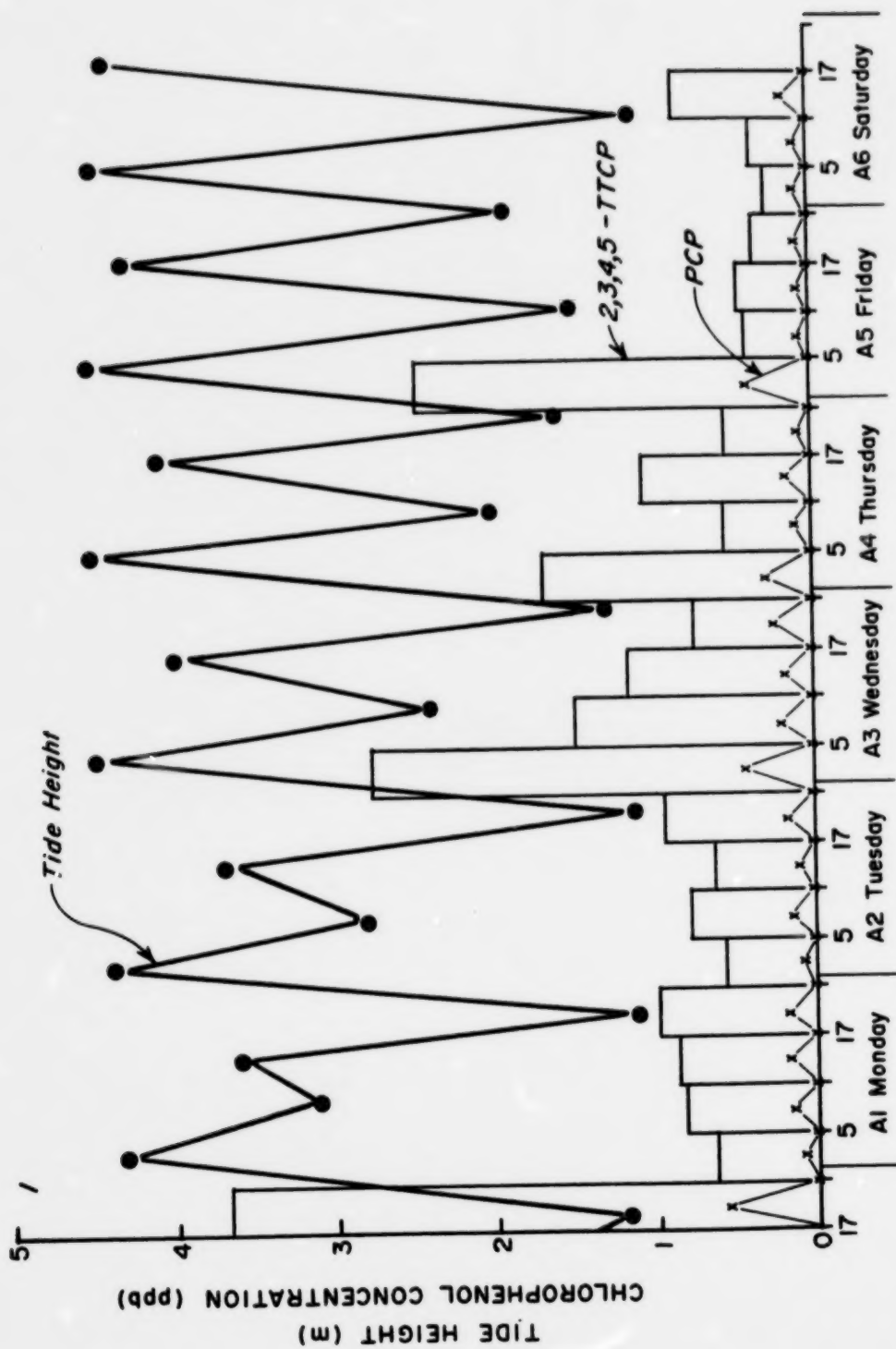


Figure 16



2.2 Organic Contaminants in Sediments

Since most organic contaminants are not very water soluble, they tend to adsorb to suspended and bed sediments rapidly. Therefore, sediment analysis has been used widely to document pollution of the aquatic environment by organic contaminants.

As part of the Fraser River Estuary Study, Garrett (1980) reviewed the information on organic contaminants. Table 8 summarizes some of the main studies that were conducted on organic contaminants in the Fraser estuary and tributary sediments. Most of these studies were investigations of specific groups of organic compounds in localized areas of the Fraser. The concentrations of most chlorinated pesticides appeared quite low. This could have been attributable to tight regulations on many compounds such as DDT since the early 1970s, as well as the large dilution of the Fraser system, especially during freshet when large quantities of sediment are transported. Some high concentrations of polychlorinated biphenyls have been reported. These higher concentrations have been associated with specific industrial discharges or with urbanized areas which receive stormwater discharges. Benzopyrene, a PAH, which has been reported to have carcinogenic properties, has been found in relatively high concentrations in some areas and has been related to the use of creosote preservatives on wooden pilings (Dunn and Stich, 1976).

More recently, a survey of organic contaminants was made in composite sediment samples from 10 areas of the Fraser estuary from backwater sloughs to the open banks (Hall et al., 1984). This study used GC/MS to survey for the presence of 14 compounds in the acidic fraction and 30 compounds in the base-neutral fraction. Table 9 summarizes the organic contaminants that

Table 8. Organic Contaminants in Sediments⁽¹⁾

Contaminant Group	Area	Compound	Concentration ($\mu\text{g.kg}^{-1}$)	Reference
Chlorinated Hydrocarbons	Brunette R. Sediments (1973-74)	DDT	4-90	Hall et al. (1976)
		DDE	5-6	
		DDD	7-40	
		chlordanes	3-44	
		PCBs	37-780	
	Fraser Est.	PCBs	< 5-1300	EPS (unpublished)
		pesticides	< detection limit	
Polycyclic Aromatic Hydrocarbons (PAHs)	Still Creek	(11)	0.2-38.5	Morton (1983)
	Iona Is. (S. Jetty)	benzopyrene	< 1 → 121	Dunn & Stich (1976)
	"	naphthalene	22	Rogers (1979)
Chlorophenols	Fraser Est. (4 sites)	TTCP & PCP	tr. → 90	E.V.S. (1979)
		pentachloroanisole	tr. → 100	"
Phthalate Esters	Iona Is. (S. Jetty)	(4)	16 → 209	Rogers (1979)

(1) Data reviewed by Garrett (1980)

TABLE 9: TRACE ORGANIC CONTAMINANTS IN SEDIMENTS⁽¹⁾

COMPOUND	1	2	3	4	5	6	7	8	9	10
Phthalates										
Diethyl	+		160	+		+	+	+	+	+
Di-n-butyl-	+	+	300		105	220	446	+	+	64
Bis(2-ethylhexyl)-		50	595		21	+	170	+	+	57
Butylbenzyl-								196		
PAH's										
Naphthalene			+			+	+	+	+	
Acenaphthene		+		+		+				
Fluorene			98	+						
Phenanthrene		26	46	18	13	24	+	75	32	35
Anthracene	+						+	3		
Fluoranthene	+	61	+	38	23	79	+	68	139	53
Pyrene	+	102	+	89	43	174	311	258	335	108
Benzo(a)anthracene		6				+		+	18	
Chrysene		+				4		+	+	
Acidic Compounds										
Phenol	56		28	7	8		13	28	9	25

(1) all values in ng/g dry wt., + = trace

(2) Sampling Stations:

- | | | |
|---------------------|----------------------|------------------|
| 1 - Roberts Bank | 5 - Steveston Island | 8 - Point Grey |
| 2 - Ladner Harbour | 6 - Middle Arm | 9 - North Arm |
| 3 - Crescent Slough | 7 - Iona Island | 10 - Steel Creek |
| 4 - Annacis Island | | |

were identified in surface sediments. The only acidic compound identified was phenol which was found in eight sediment samples. Phthalate esters and PAHs were the main organic contaminants identified in sediments. The di-n-butyl and bis (2-ethylhexyl)- phthalates were the most frequently identified plasticizers, and the sediments from Crescent Slough and Sturgeon Banks (adjacent to Iona Island) contained the highest phthalate concentrations. Of the nine PAHs that were identified, phenanthrene, fluoranthene and pyrene occurred most frequently and the highest levels appeared to be at the North Arm and Point Grey sampling sites. A comparison of base/neutral organic contaminants in the Fraser estuary and two marine areas (False Creek and Burrard Inlet) adjacent to Vancouver shows much lower contaminant levels associated with the Fraser estuary sediments (Table 10). This is probably attributable to the sediment transport in the river during freshet when contaminated sediments will be covered with fresh upstream deposits or diluted by dispersion throughout the lower estuary and Strait of Georgia.

2.3 Organic Contaminants in Aquatic Organisms

In the early 1970s, most research on organic contaminants in aquatic organisms was focused on the persistent chlorinated pesticides and PCBs (see Bawden et al., 1973 for chlorinated hydrocarbons in crabs and Johnston et al., 1975 for chlorinated hydrocarbons in fish tissue). Bawden et al., 1973 reported p,p'-DDE, heptachlor epoxide and PCBs (Aroclor 1254) in crabs collected from Sturgeon and Roberts Banks (Table 11). PCBs were the most prevalent chlorinated hydrocarbon contaminants in the crabs. The same chlorinated hydrocarbon residues were identified in fish collected from the lower Fraser (Johnston et al., 1975). There were higher concentrations of

Table 10. Comparison of Selected Base/Neutral Contaminants
in Surface Sediments⁽¹⁾

Compound	Sediment Source		
	Fraser Estuary	False ⁽²⁾ Creek	Burrard ⁽²⁾ Inlet
Di-n-butylphthalate	64	200	240
Bis(2-ethylhexyl) phthalate	35	1770	770
Naphthalene	+	460	420
Phenanthrene	25	920	2140
Fluoranthene	46	1670	2290
Pyrene	105	3470	2680
Benzo(a)anthracene		890	530

(1) median values in ng/g dry weight, + = trace
Fraser Estuary n = 10, False Creek and Burrard Inlet n = 9

(2) Hall et al. (1983)

Table 11. Chlorinated Hydrocarbons in Crabs

Compound	Sturgeon Bank	Roberts Bank
P,P'-DDE	23-295	4-144
Heptachlor epoxide	7-22	4-19
PCBs (Aroclor 1254)	154-2100	170-1375

Bawden et al. (1973), $\mu\text{g.kg}^{-1}$ dry wt.

Table 12. Organic Contaminants in Clams and Crabs from Banks

Contaminants	Concentration ($\mu\text{g.kg}^{-1}$ wet wt.)
PCBs	0.05 - 2100
Phthalate Esters	36 - 1600
PAHs (selected n=5)	1 - 112

Rogers (1979)

these contaminants in fish collected from the lower reaches of the river adjacent to the urbanized estuary (see Figure 17 for chlorinated hydrocarbons in northern squawfish).

More recently, Rogers (1979) has analyzed clams and crabs from the banks of the estuary for organic contaminants. He identified PCBs and phthalate esters as important contaminants (Table 12). Surveys for other contaminants have identified hexachlorobenzene, tetrachlorophenol and pentachlorophenol in fish tissue from different reaches of the lower Fraser (Table 13 - data from Garrett, 1980). Singleton (1983) identified three phthalate esters in muscle tissue from largescale suckers collected from the lower Fraser (Figure 18), but there did not appear to be any significant regional distribution of these compounds to help identify possible source areas.

In their general survey of organic contaminants in the Fraser estuary, Hall et al. (1984) identified PAHs, phthalates, chlorobenzenes (Table 14) and chlorinated phenols (Table 15) in the tissue of starry flounders and peamouth chub (only at Station 3). The same phthalate esters that occurred in sediments [diethyl-, di-n-butyl, and bis (2-ethylhexyl)] were most prevalent in fish tissue with some tissue samples also containing benzylbutylphthalate. The PAHs in fish tissue were not as widely distributed as was found in surface sediments. Of the 16 PAHs that were quantitated, naphthalene was the most common polycyclic found in fish followed by fluoranthene and benzo(a)pyrene which were identified in three tissue samples. Fish tissue in contrast to sediments contained high levels of several chlorinated phenols. The higher chlorinated phenols, which are also more prevalent in the wood preservatives, occurred in the highest

Figure 17

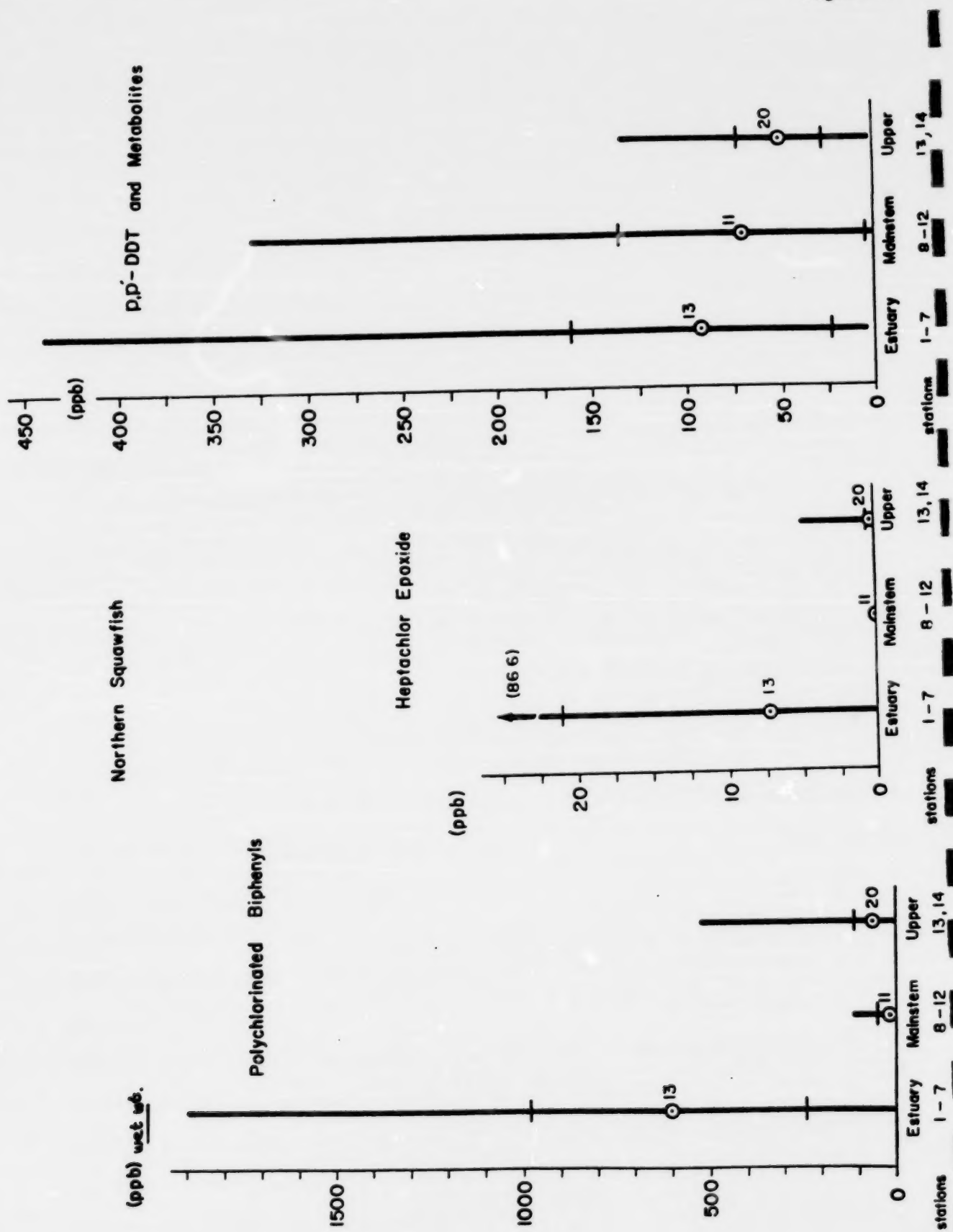


Table 13. Chlorinated Benzenes and Phenols in Fish Tissue

Area	Hexachlorobenzene	Tetrachlorophenol	Pentachlorophenol
North Arm	1-13	18-62	tr-60
South Arm	tr-13	tr-37	4-125
Upper Estuary	tr-7	ND	8-28
Chilliwack Area	1-19	22	14-48
Hope Area	1-6	ND	4-33

Garrett (1980) $\mu\text{g.kg}^{-1}$ dry wt.

PHTHALATE ESTER CONCENTRATIONS IN THE MUSCLE TISSUE OF LARGESCALE SUCKERS FROM THE FRASER RIVER

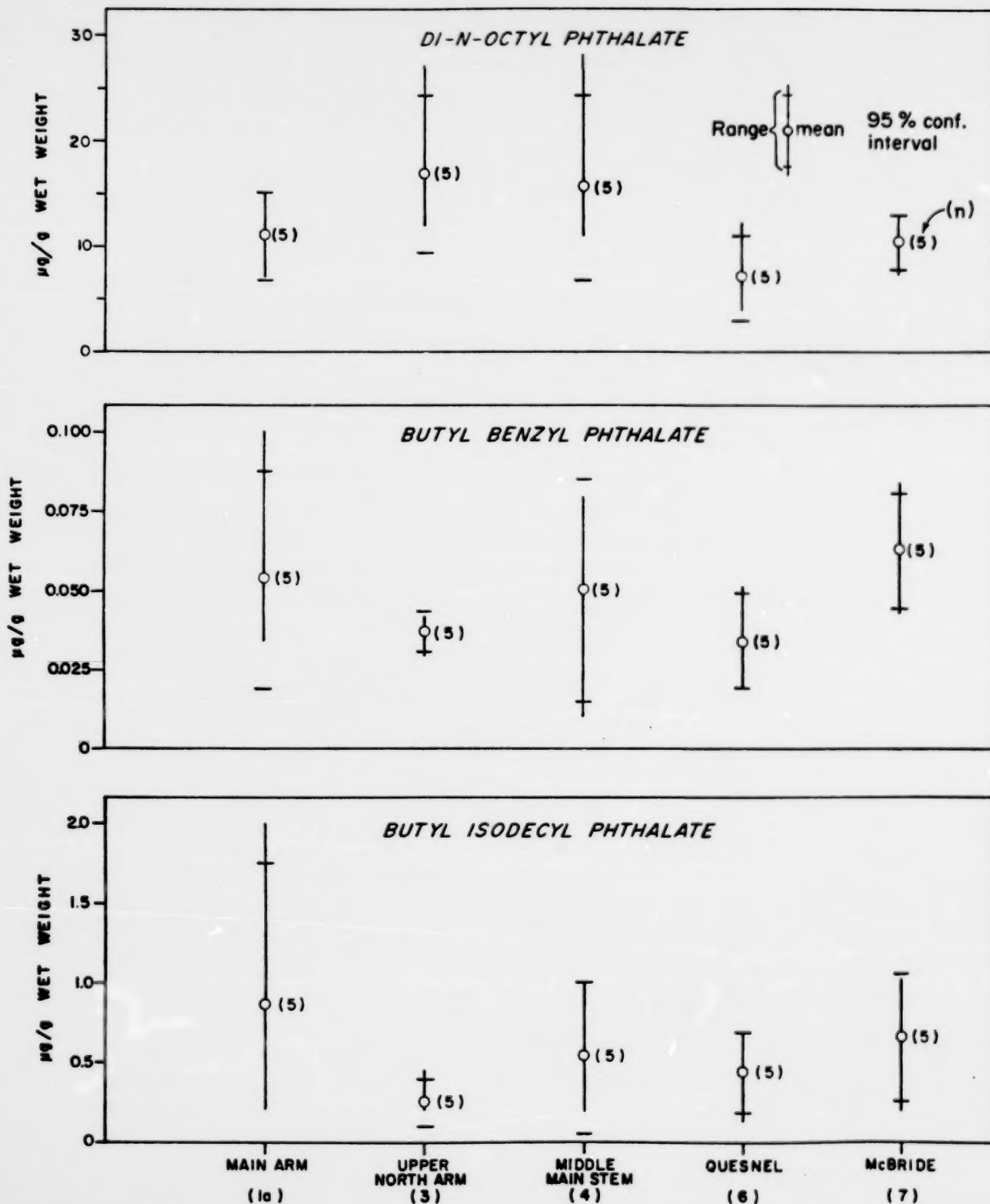


TABLE 14: BASE NEUTRAL ORGANIC CONTAMINANTS IN FISH (1)

COMPOUND	1	2	3	4	5	6	7	8	9
Chlorobenzenes									
1,4-Dichloro-		32							21
1,2-Dichloro-		6		101					
Phthalates									
Dimethyl-			14						74
Diet'yl	72	+	51	284	313	124	237	136	257
Di-n-butyl-	73	15			518	+	622	128	242
Bis(2-ethylhexyl)-	8	27	24	25	93	1057	588	19	156
Benzylbutyl-			14	316	170			139	100
PAH's									
Naphthalene	43	+	34	+	109			8	19
Fluorene			12						
Phenanthrene			10		3				
Anthracene					143				
Fluoranthene			5		18				204
Pyrene			17						8
Chrysene			8		302				
Benzo(a)pyrene			27		135			36	
Benzo(g,h,i)perylene			58		+				

(1) all values in ng/g dry wt., + = trace

(2) Sampling Stations:

- | | | |
|---------------------|----------------------|-----------------|
| 1 - Roberts Bank | 4 - Annacis Island | 7 - Iona Island |
| 2 - Ladner Harbour | 5 - Steveston Island | 8 - Point Grey |
| 3 - Crescent Slough | 6 - Middle Arm | 9 - North Arm |

TABLE 15: ACIDIC ORGANIC CONTAMINANTS IN FISH (1)

COMPOUND	SAMPLING STATION(2)								
	1	2	3	4	5	6	7	8	9
Phenol	49	12	320	112	15	4	105	9	33
2-Chlorophenol			123		6		40	3	13
2,4-Dichlorophenol		337	182	736	41	6	217	94	74
2,4,6-Trichlorophenol		519	365	1442	493	357	602	547	57
Tetrachlorophenol		1908	2522	1732	1562	194	2084	587	952
Pentachlorophenol		1140	2768	2329	2182	773	2111	1093	933

(1) all values in ng/g dry wt., + = trace

(2) Sampling Stations:

- | | | |
|---------------------|----------------------|-----------------|
| 1 - Roberts Bank | 4 - Annacis Island | 7 - Iona Island |
| 2 - Ladner Harbour | 5 - Steveston Island | 8 - Point Grey |
| 3 - Crescent Slough | 6 - Middle Arm | 9 - North Arm |

concentrations with levels of tetrachlorophenol (2,3,4,6-TCDF) from 0.19 to 2.52 ug/g and pentachlorophenol from 0.77 to 2.77 ug/g wet weight. Recent analyses of fish tissue from the North Arm of the Fraser for chlorinated phenols identified the same compounds, but concentrations were considerably lower than was found by Hall et al., 1984, which raises some concern about analytical quantitation of these substances and will require some future substantiation (Carey, unpublished data).

CONCLUSIONS

Although this selective review indicates that there is considerable information available on many toxic contaminants in the lower Fraser River system, much of this information is relatively old (i.e. early 1970s). This early information concentrated upon environmental concerns of the period such as mercury and pesticide pollution problems. Recent advances in analytical techniques such as GC/MS have allowed scientists to determine a wide variety of organic contaminants, but these analyses are still very expensive which has hampered an adequate assessment of organic contaminant pollution in the estuary. Future monitors will undoubtedly have to be highly selective due to the cost of analyses and government cutbacks in environmental research. Monitoring programs will have to be carefully thought out if they are going to be effective in managing toxic materials in the estuary. This problem becomes even more difficult to manage when consideration is given to the sporadic nature of many of these pollutants in the Fraser and the hydraulic complexity of the environment that must be sampled.

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SESSION I

IDENTIFICATION OF TOXIC CHEMICALS AND DETERMINATION OF SOURCES

Facilitator: Fred G. Claggett, Environmental Protection Service
Rapporteur: Allen Furnell, Dept. of Biological Sciences, S.F.U.

INTRODUCTION

The lower Fraser River and its estuary receive large quantities of wastes from urbanized and industrial activities. The identification of toxic chemicals and the determination of their sources is imperative to any plan of water quality monitoring and management. The Session I workshop on toxic chemicals research needs of the lower Fraser River defined two objectives. The first was to identify high priority toxic chemicals. The second objective was to define sources of input within the basin. By considering the past and current inventories of various sources future data needs were identified.

PRIORITY TOXIC CHEMICALS

The diverse nature of activities in the lower Fraser River valley produces a wide range of toxic chemicals. The first objective was to define the compounds of greatest concern. These are chemicals that occur in trace quantities but are extremely toxic. They can be divided into elemental substances and organic compounds. In the former category, the heavy metals such as copper, lead, mercury, cadmium and zinc are of greatest concern. Polychlorinated biphenyls (PCBs), chlorinated phenols and polynuclear aromatic hydrocarbons (PAHs) were determined to be the highest priority organic compounds.

SIGNIFICANT LEVELS

There are some fundamental criteria that must be defined before any management plan can be implemented, the most pertinent of which is what can be considered as significant levels of these compounds. Possibly, the more deeply underlying definition to evaluate is acute and chronic toxicity and bioaccumulation. This implies that if a chemical can be graded for toxicity, then acceptable levels for these compounds can be defined. Within the confines of any definition of toxicity there is a need to determine the synergistic effects between different compounds. This should also include the influence of natural pathogens of biota with these toxic compounds.

ANALYTICAL TECHNIQUES

The members of the workshop expressed a need to define suitable analytical techniques. This is especially true for the PAHs. Once a technique is selected, then quality control must be instituted with cross laboratory checks. By targeting analytical techniques for specific compounds, the cost of monitoring sources could be reduced in future research. Such an approach aroused some concern about whether the targeted compounds are the toxic agents. This fear stemmed from the speciation of chemicals in the natural environment and the example of dioxins contaminating batches of halogenated phenoxyacetic acids (like 2,4,5-T).

SUMMARY OF EXISTING INFORMATION

I. Point source inputs of organic and inorganic constituents:

1. Domestic sewers

- (a) Annacis sewage treatment plant screening for priority pollutants
 - an unpublished report by Environmental Protection Service (EPS) - may be obtained on request to GVS&DD. Greater Vancouver Sewage and Drainage District (GVS&DD) 4330 Kingsway, Burnaby, B.C.
- (b) Iona Island sewage treatment reports (GVS&DD)
 - data reported to Waste Management Branch (WMB), B.C. Ministry of Environment, as part of the effluent permit requirements, available from either WMB files or GVS&DD.
- (c) Municipal and GVS&DD monitoring of industrial discharges to sewer
 - data gathered, or reported relative to source control programs. May be obtained from GVS&DD or from municipality by-law enforcement groups.
- (d) Annual lead usage in gasoline (EPS)
 - contact E. Wituschek, Head of Air Pollution Programs, EPS, Kapilano 100, Park Royal, West Vancouver, B.C., V7T 1A2.
- (e) Metal contribution from domestic water supply (Greater Vancouver Regional District - GVRD)
 - routine monitoring, plus special studies related to corrosion due to soft water supplies.
Contact: Hans Krause, GVRD, 4330 Kingsway, Burnaby, B.C.
- (f) Permit Monitoring Data - Waste Management Branch, B.C. Ministry of Environment, 15326 - 103A Ave., Surrey, B.C. V3R 7A2
 - company reported and audit information on each file.

2. Stormwater

- Combined system overflow
 - (a) Ferguson, K.D., Hall, K.J. Fraser River Estuary Study, Water Quality, Stormwater Discharges, 1979

(b) City of Vancouver Report

- little information available, except that the City Engineering Department has undertaken a detailed study.

- Separate stormwater systems

(a) Inventory of Storm Sewers (Ken Hall - 1979)

- available from Westwater Research Centre, 1933 West Mall, U.B.C., Vancouver, B.C. V6T 1W5.

(b) Inventory of 140 Outfalls (WMB-1980)

- available through Dr. M. Clark, Waste Management Branch, Ministry of Environment, 810 Blanshard Street, Victoria, B.C., V8V 1X5

(c) Toxicity of Stormwater Discharges (U.B.C. Civil Engineering Thesis, 1982)

- contact D. Mavinie - U.B.C. Civil Engineering Department.

(d) Loading from Two Outfalls (Aquatic Studies)

- available from L. Swain, Water Management Branch, Ministry of Environment, 765 Broughton Street, Victoria, B.C. V8V 1X5.

(e) Ontario Urban Runoff Studies

- available from EPS Library.

(f) Environmental Protection Agency Urban Runoff Studies

- published in 1984 Water Pollution Control Federation (WPCF) Journal, available through most technical libraries. (EPS Library) or from WPCF.

3. Industrial discharges

(a) Permit Monitoring Data

- available through WMB Surrey (Prad Khare)

(b) PCB data for Belkin Paper

- available through WBM Surrey (Prad Khare) or EPS (Ken Wile)

(c) Fraser River Estuary Water Quality Report

- (d) PCB Use Inventory
 - selected reports available through EPS (Ken Wile)
- (e) CCA Use Inventory
 - inventory of priority Contaminants Act Chemicals
 - available through EPS (Ken Wile)
- (f) Toxic Chemicals Profile
 - inventory of toxic chemicals uses in B.C; draft completed by EPS. 1982

4. Drainage ditches - Agriculture

- (a) Pesticide Survey
 - Ken Hall, 1976, Westwater Research Centre, U.B.C.
- (b) Survey of 3 widely used pesticides
 - contact Mike Wan, EPS

5. Landfills

- (a) Fraser River Harbour Commission (Richmond Landfill)
 - by Atwater, available from EPS Library
- (b) Refuse and Effluent Permit Data
 - WMB, Surrey
- (c) Selected Monitoring Data
 - contact D. Ellis, EPS
- (d) Surrey Landfill Study
 - contact Atwater Civil Engineering, U.B.C.

II. Non-point source inputs (most covered by the point source inputs)

1. Atmospheric

- (a) Emission data (Barrie Mills, GVRD; Rick Wilson, MOE)
- (b) National Air Pollution Surveillance (NAPS) data (monthly, annual and trend reports, EPS)
- (c) Kanaka Creek study - ongoing (Inland Waters Directorate)

(d) Lower Mainland Acid Rain study (Don Faulkner, Atmospheric Environment Service; Mike Flynn, Department of Fisheries and Oceans)

(e) PAHs ambient air concentration (Ed Wituschek, EPS)

2. Groundwater

- little is known because of the permeable nature of soils in the basin

INFORMATION GAPS

I. Point Source inputs

1. Domestic sewers
 - monitoring for trace organics
2. Stormwater
 - contaminant loadings under varying storm conditions
 - pathogen inventory
 - PAH monitoring, loadings, and source inventory
3. Industrial effluents
 - review of effluent permits with chemical use inventories
 - inventory of "solid" inputs from marinas, boat builders, bulk terminals, bridge maintenance, etc.
4. Drainage ditches
 - update of 1976 Ken Hall report
 - monitoring and inventory of feedlot effluents
 - trace organics in landfill leachates

II. Non-point source inputs

1. Atmospheric
 - determine portion of stormwater loadings from the atmosphere
2. Groundwater
 - further monitoring at sites such as Chatterton Petrochemicals, Koppers, Tree Island Steel, oil sludge farms

RESEARCH NEEDS

The research needs are basically the same as those items identified as Information Gaps.

The workshop identified the effluents of most concern as those containing heavy metals, chlorinated phenols, PCBs and PAHs. Almost all sources contained

one or more of these high priority chemicals. The following sources are listed in the order of priority for future research:

1. inputs from domestic sewers
2. inputs from stormwater sewers
3. input from groundwater sources
4. landfill leachates

Research priorities within these categories should be based on priority chemical use patterns.

SESSION II

HYDRODYNAMICS AND SEDIMENT TRANSPORT OF THE LOWER FRASER RIVER

Facilitator: Al Ages, Institute of Ocean Sciences, D.F.O.

Rapporteur: Patrick O'Brien, Dept. of Oceanography, U.B.C.

INTRODUCTION

The Fraser River is characterised by a high loading of suspended particulate material and by a strong tidal influence. Approximately 40% of the Fraser's sediment load is sand (grain size between 0.062 and 2.00 mm); clay and silt constitute approximately 60% of the Fraser's suspended load.

Residence times of water in the Fraser may vary significantly, depending upon tides and river discharges. For instance, a substance released at Annacis Island may leave the Main Arm at Sandheads after six hours during the freshet, or after sixty hours during periods of low river discharge.

Saltwater intrusion influences the water movement in the lower reaches: an incoming tide generates an upstream flow of saltwater under the surface flow of freshwater, which reverses direction at a high tide when river discharges are moderate to low. The salt water enters the river in the form of a wedge, which remains near the mouth during the freshet (June), but may intrude the Main Arm as far as New Westminster at a very low river discharge (February, March). In the North Arm, the salt wedge will, at low discharges, travel upstream beyond the east corner of Mitchell Island.

The transport of suspended materials will be affected to varying degrees by tidal activity, discharge volume, velocity, and salinity intrusion, although the exact influence of the salt wedge upon sediment transport is not clearly understood at this time.

Distribution of Water Flow in the Fraser River

The water flow studies discussed at this workshop concentrated primarily on the stretch of river between New Westminster and the mouth of the Fraser, a distance of 35 km. At New Westminster, the river splits into three separate flows, the North Arm, the Annacis Channel and the Annieville Channel (the Main Arm). Further downstream, a small portion of the Main Arm branches off through the Ladner Reach to feed a delta of shallow channels and marshes. Some of this water flows through Canoe Pass into the Strait of Georgia while the remainder rejoins the Main Arm near Steveston. West of Steveston, the river is channelled through the tidal flats by the Steveston Jetty and the Albion Dike. During the freshet, a significant portion of the outflow is discharged onto Roberts Bank over the Albion Dike.

In the past 15 years, some flow data have been collected in these split areas by Water Survey of Canada, in particular at the trifurcation below New Westminster. The distribution of water flow between the three channels at the present time is believed to be:

- i) North Arm: 12-14% of the total flow
- ii) Annacis Channel: 8-10% of the total flow
- iii) Annieville Channel: 74-80% of the total flow

It was suggested during the workshop that a comparison between these percentages and the ones obtained in earlier years indicated an increase in flow into the North Arm, possibly caused by dredging. This suggestion was disputed by some of the participants who felt that more observations at a variety of hydrodynamic conditions were needed to deal with this important issue.

A similar need for more flow information exists in the Ladner and Albion Dike areas.

The Sediment Loading: An Evaluation

The mass of sediment transported by the Fraser River is a function of stream discharge, velocity and supply. The sediment load shows a pronounced seasonal distribution; the highest loads are associated with the spring freshet (May-July).

From Water Survey of Canada records, it is estimated that the mean annual sediment load of the Fraser River at Port Mann is 19.5×10^6 tonnes/year; of this 1.5×10^6 of the total sediment load is transported as bedload (that material transported on or near the streambed by a rolling, sliding or saltation mechanism). The remaining portion (18×10^6 tonnes/year) of the average total load is transported as suspended load (that material carried in suspension by the turbulent components of the fluid or by Brownian movement).

An accurate evaluation of the distribution of the sediment load at the trifurcation site has yet to be established. Measurements to this effect are planned for the future.

(a) Sand Fraction (particles 0.062-2.0 mm in diameter)

Sand makes up approximately 40% of the total load or 7.5×10^6 tonnes/year. The Fraser River from approximately Mission to the mouth is classified as a sand bed river. Moving in a downstream direction, there is a trend towards decreasing particle size of the bed material associated with a general decrease in stream velocities. The decreased velocities cause the sand-sized particles to fall out of suspension to form part of the bed load or bed material. The accumulation of this material in the river channel can cause significant problems for navigation.

(b) Clay/Silt Fraction (particles < 0.062 mm in diameter)

This fraction is estimated to make up 60% of the total load or 12.0×10^6 tonnes/year at Port Mann. It is often classified as the washload (that portion of the suspended load which is not found in appreciable quantities in the bed). The transport of this material is usually limited by upstream supply rather than hydraulic considerations. The clay/silt fraction of the load has the largest surface area. Organic and inorganic molecules and heavy metals may bind to the surface of the particles chemically or electrically and be transported by the fluid. Most of the clay/silt material is transported as washload to the Strait of Georgia where it forms the Fraser river plume. An unknown quantity of the clay/silt load will fall out of suspension in slack water areas of the Fraser River, e.g. sloughs, side channels and backwater areas. As this material accumulates over time, there will be an increased concentration of heavy metals and organic and inorganic substances. This has already been observed to occur.

Dredging

Public Works Canada operates an ongoing dredging program on the Fraser River for the maintenance and improvements to the navigation channel by both in-house and contract dredging. In total, approximately three (3) million cubic metres a year is dredged from the river. In addition, there are other dredgings carried out by industries to acquire sand from the river for municipal and industrial uses. This amounts to about 2.3 million cubic metres each year, of which about 1.5 million cubic metres contributes to the improvement of channel maintenance. It was noted that the total volume of sand dredged from the lower reach of the river exceeds the total sand supply coming down from the upper river. To date, Public Works Canada has not yet achieved the committed depths for a 10.7 m (or 35 ft.) draught channel for the deepsea navigation in the South Arm of the Fraser River. This dredging will be continued until a 10.7 m draught channel is achieved. Subsequently, a scaled-down effort will be maintained to balance dredging and infill.

Water Quality Considerations

Identification and quantification of sources, pathways and sinks of toxic material present in the Fraser River and their impact on biota were noted as matters of immediate concern. Toxic substances would include trace metals (e.g. Hg, Cd, Cu, Ni, Zn, and Pb), and organic compounds (e.g. polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides, dioxins, etc.). Many of the toxic substances known to occur in the Fraser system will bind to the fine fraction of the sediment load (i.e. the clay/silt fraction), while others will be water soluble; toxic substances from both phases can accumulate in and be detrimental to aquatic biota.

Accumulations of toxic materials will occur in locations of slow-moving water since it is here that the clays and silts will settle out of suspension. This is known to occur in some areas along the Fraser River such as Ladner Slough.

RECOMMENDATIONS (not in order of priority)

Water Quality

- i) Toxic compounds entering and being retained in the Fraser River system must be identified and quantified.
- ii) A determination of the mechanism and phase of transport, of the binding potential for toxic substances, and of the ultimate fate (including deposition zones) for the clay/silt materials is needed.
- iii) Modelling the behaviour of major effluents on the Fraser River system would help identify areas vulnerable to contamination.
- iv) Guidelines should be implemented to control chemicals entering the sewer systems. When feasible, discharge of potentially dangerous materials should be limited to periods of maximum dilution and minimum residence time.

Hydrodynamics

- i) An intensified program of current measurements in the trifurcation below New Westminster is needed to assess the flow distribution in this area. The program should be carried out at a variety of discharges and tidal conditions.
- ii) Similarly, although of a somewhat lower priority, the flow distribution in the Ladner area should be determined for a reasonably large range of hydrodynamic conditions.
- iii) An attempt should be made to estimate the overflow across Albion Dike during high discharges.
- iv) Since water quality concerns are mainly with pathway and deposition of silt and clay, a program to measure sediment loads should be linked with the flow observations wherever possible. In addition, a geomorphological program is suggested to study the deposition of clays and silts in the slack water areas (e.g. sloughs and side channels).
- v) Research in hydrodynamics and sediment transport as related to toxic chemicals should be undertaken cooperatively with experts in other disciplines such as chemistry and biology.

SESSION III

CHEMICAL PATHWAYS

Facilitator: John Carey, N.W.R.I., Burlington, Ontario

Rapporteur: Christina Jacob, Environmental Engineering, U.B.C.

Research into the pathways of chemicals in the environment can be divided into four general study areas. They are:

1. Source
2. Transport
3. Accumulation
4. Fate

Source

Source was the topic of another session and was, therefore, not discussed in detail by the pathways work group. It was pointed out, however, that the type of source can sometimes determine subsequent pathways of a chemical. For example, polycyclic aromatic hydrocarbons (PAHs) often enter the aquatic system adsorbed in particles. Desorption kinetics for these compounds are so slow that the pathways of accumulation and degradation of PAHs studied in solution in the laboratory are inappropriate for the real system.

Transport

In the Fraser estuary, the driving forces for contaminant movement are currents and tides. A critical question concerns the distribution of contaminants between solid and solution phases. Depending on this distribution, contaminant transport will be governed either by water movement or particle dynamics or both. For organic contaminants, recent research⁽¹⁾

(1) J.J. Hassett, J.C. Means, W.L. Banwart and S.G. Wood, Sorption properties of sediments and energy-related pollutants, U.S. EPA, EPA-600/3-80-041, 1980; S.W. Karickhoff, Semi-empirical estimation of sorption of hydrophobic pollutants on natural sediments and soils, Chemosphere; 10, 833, 1981.

indicates that an important parameter in controlling the extent of contaminant sorption is the fraction of organic carbon, f_{oc} , in the suspended material. The distribution coefficient, K_d , for a specific organic contaminant is defined as:

$$K_d = C_p / C_w$$

where C_p is the concentration of the contaminant associated with some weight of particle and C_w is the concentration of the contaminant in an equal weight of water. Since K_d depends on the type of suspended material, it will vary from system to system and even spatially and temporally within a system. In many cases, it is possible to 'normalize' these results by use of the expression:

$$K_d = K_{oc} \times f_{oc}$$

where K_{oc} is the 'organic carbon normalized' distribution coefficient for a contaminant. This relationship has been observed to be inappropriate for the Niagara River, and its applicability to the Fraser system should be investigated.

For inorganic contaminants, important sorption processes include⁽²⁾: 1. ion exchange processes at negatively charged surfaces; 2. co-precipitation with iron and manganese hydrous oxides; and 3. complexation with bound or particle associated organic matter.

(2) U. Forstner, Accumulative phases for heavy metals in limnic sediments, *Hydrobiologia*, 91, 269, 1982; U. Forstner & W. Solomons, Trace-element speciation in surface waters; interactions with particulate matter; in, Trace- element speciation in surface waters and its ecological implications, G.G. Leppard, ed., Plenum, 1983.

These mechanisms control not only distribution, but also bioavailability of inorganic contaminants. The relative importance of each of these mechanisms can vary seasonally or spatially within the estuary; for example, the precipitation of hydrous iron or manganese oxides can be most important at the salt/fresh water interface. They may, therefore, be of particular importance in the 'salt-wedge' region of the estuary. The processes controlling sorption of inorganic contaminants should be investigated, with particular attention to seasonal and spatial variations.

Several recent reviews⁽³⁾ may be useful references to obtain an overview of these processes. The main research recommendations in this area are:

- characterize the seasonal aspects of the suspended material: type of particles (physical and biological types and organic carbon content) and how do they affect sorption processes.
- precipitation of metal oxides as affecting the partition of various chemicals in the water system, particularly at the fresh/salt water interface.
- physical state of contaminants at source (when they enter the water system and how this state affects transportation and fate). Evaluation of rates of sorption and desorption.
- evaluation of the technique of centrifuging as a method of sampling the suspended solids when they contain a high percentage of biomass which is destroyed by this sampling method. Find an alternative method.

(3) B.T. Hart, Uptake of trace metals by sediments and suspended particulates: A review. *Hydrobiologia*, 91, 299, 1982; C.R. Olsen, N.H. Cutshall and I.L. Larsen, Pollutant-particle associations and dynamics in coastal marine environments: A review. *Marine chemistry*, 11, 501, 1982.

Accumulation

Organic contaminant uptake by organisms has often been treated by assuming equilibrium conditions and calculating a distribution coefficient, i.e.

$$K_b = C_b / C_w$$

where K_b is the distribution coefficient

C_b is the concentration in the biota; and

C_w is the concentration of the pollutant in water

This distribution coefficient is often called the Biological Concentration Factor or BCF. This factor is sometimes subdivided into independent factors for distinct types of tissue:

$$BCF = \frac{1}{C_w} \sum_j Y_j C_j$$

where C_j is the pollutant concentration in a tissue; and

Y_j is the fraction of total body weight of that tissue.

It is necessary to differentiate compounds that bioconcentrate from those that bioaccumulate along a food chain. The former may be treated as an equilibrium situation, while the latter often cannot. For example, chlorophenols appear to accumulate in fish directly from the water and are rapidly absorbed and excreted. Thus, bioaccumulation of chlorophenols may be treated as an equilibrium situation. By contrast, very hydrophobic substances of limited water solubility are concentrated via the food chain and the equilibrium approach is less valid. Biota are often better media to sample than water since concentrations can be considerably higher in biota and the numbers can be more relevant to health considerations if a route of exposure, i.e. consumption, is present. Organisms, such as crayfish, starry flounder and shrimp, are present in the Fraser estuary and are consumed by people and other organisms such as young salmon. One organism, Neomysis, is

consumed by both people and salmon and deserves consideration as a useful biomonitor species. It was pointed out by the group that the analysis of organic contaminants in fish is difficult and there is often considerable variation between laboratories. An interlaboratory quality control program and a standard reference material for biota could help laboratories develop capability in this area, and ensure consistent data for management decisions. Therefore, the following areas of research were identified by the work group:

- determination of the bioconcentration factors of the priority pollutants specific to the Fraser River estuary for species existent in the Fraser River, which are consumed as food.
- standardization of the extraction and analytical techniques in order to make comparison of results more effective.
- development of standard reference material.

With regard to metals, levels in biota appear to be controlled by the speciation of a metal and not its total concentration. Therefore, methods for the assessment of bioavailability of metals are required. Synergistic effects of metals and metal/organic contaminants also deserve consideration. Clams may be good biomonitors for metals, and their use for this purpose should be evaluated. Finally, the fresh/salt water interface is an area where many metals undergo changes in speciation. The effect on bioavailability of these changes should be evaluated.

Fate

Organic contaminants can be removed from the aquatic environment by a number of pathways. The major ones are:

1. hydrolysis
2. biodegradation
3. volatilization
4. photodegradation

The rates at which any of these processes proceed depend both on the chemical properties of the contaminant and the physical properties of the system under investigation. For example, hydrolysis rates are affected by the presence of acids or bases so that the rate can be expressed as:

$$\text{rate} = k_H [H^+] + k_{OH} [OH^-] + k_h$$

where k_H is the rate constant for an acid catalysed reaction

k_{OH} is the rate constant for a base catalysed reaction

and k_h is rate constant for the uncatalysed hydrolysis.

If these rate constants are known for a given pollutant, and the pH of the system is known, a prediction of the half-life of the pollutant can be made. The hydrolysis half-life of a chemical will depend mostly on chemical properties and to a lesser extent in ecosystem characteristics.

Other processes such as volatilization and photodegradation depend on both chemical properties and system characteristics. For example, for volatilization, the vapour pressure of the substance (often estimated from Henry's law of constants) and the extent of mixing and turnover determine the importance of this pathway. The rates of the concentration of a contaminant in air at the air/water interface (C_{Ai}) to the concentration in water at the interface (C_{Wi}) is the air-water partition coefficient and is equal to the Henry's Law of Constant (H) divided by the gas constant R and by the absolute temperature T., i.e.

$$\frac{C_{Ai}}{C_{Wi}} = K_{AW} = \frac{H}{RT}$$

For photodegradation, in addition to the chemical's sunlight quantum yield, the photochemical half-life is estimated using system parameters, such as amount of light available, system depth and the presence of other light absorbing species. The effect on indirect photolysis (i.e. reaction of the pollutant with photochemically generated reactants) also needs to be evaluated.

Finally, with regard to biodegradation, the rate will be determined by concentration of contaminant and the concentration of organisms capable of degrading a pollutant relative to the total population of organisms. Laboratory studies performed with organisms different from those in the system under study, or under conditions where the pollutant is the sole source of some limiting nutrient, and those performed in the absence of surfaces for biodegradation such as sediment, weeds, etc. are not particularly useful in predicting biodegradation rates.

The evaluation of all of these parameters for all chemicals was felt by the work groups to be so far beyond the resources available as to require another approach. It was the consensus of the work group that several compounds should be chosen as models for detailed fate studies. Pentachlorophenol and 2,3,4,6 - Tetrachlorophenol seem particularly good candidates for the Fraser Estuary. These studies would then serve as a benchmark for investigations of the relative importance of the above processes for other contaminants found in the Fraser system. The recommendations of the work group are:

1. Using PCP and 2,3,4,6 TCP as models to conduct detailed fate studies.

2. Relate the transformation rates of other contaminants to PCP and 2,3,4,6 TCP using expressions such as:

a) hydrolysis rate = $k_H (H^+) + k_{OH} [OH^-] + k_h$
as defined above.

b) biodegradation rate = $k [\text{bug}] [\text{contam.}]$
where [bug] is the concentration of microorganisms capable of degrading the contaminant and [contam.] is the concentration of the contaminant.

c) volatilization rate-evaluate Henry's Law of Constants.

d) photodegradation-sunlight quantum yields.

Useful references for treatment of these areas include:

1. Hydrolysis

- (a) W. Mabey & T. Mill, Critical review of hydrolysis of organic compounds in water under environmental conditions, J. Phys. Chem. Ref. Data, 7, 383, 1978.
- (b) N.L. Wolfe, Determining the role of hydrolysis in the fate of organics in natural waters in Dynamics, Exposure and Hazard Assessment of Toxic Chemicals, R. Hague, ed., Ann Arbor Science Publishers, 1980.

2. Biodegradation

- (a) G.L. Baughman, D.F. Paris & W.C. Steen, Quantitative expression of biotransformation rate, in Biotransformation and Fate of Chemicals in the Aquatic Environment, A.W. Maki, K.L. Dickson and J. Cairns, eds., American Society for Microbiology, Pub. 1980.
- (b) M. Alexandra, Biodegradation of toxic chemicals in water and soil, in Dynamics, Exposure and Hazard Assessment of Toxic Chemicals, R. Hague, ed., Ann Arbor Science Publishers, 1980.

3. Volatilization

- (a) J.H. Smith, D.C. Bonberger & D.L. Haynes, Prediction of the volatilization rates of high volatility chemicals from natural waters, Environ. Sci. Technol, 14, 1332, 1980.
- (b) D. Mackay & A.T.K. Yeun, Mass transfer correlations for volatilization of organic solutes from water, Environ. Sci., Technol, 17, 211, 1983.
- (c) D. Mackay, W.Y. Shin, A. Bobra, J. Billington, E. Chan, A. Yeun, C. Ng and F. Szeto, Volatilization of organic pollutants from water, EPA 600/3-82-019, 1982,

4. Photodegradation

- (a) R.G. Zeppard. B.M. Cline, Rates of direct photolysis in aquatic environments, Environ. Sci. Technol., 11, 359, 1977.
- (b) W.R. Mabey, T. Mill, D.G. Hendry, B.C., Bomberger, T. Chan and J.H. Smith, Laboratory protocols for evaluating the fate of organic chemicals in air and water, EPA 600/3-82-022, 1982.

SESSION IV

EFFECTS ON BIOTA

Facilitator: Ian Birtwell, Department of Fisheries and Oceans
Rapporteur: Joyce Andrew, Department of Zoology, U.B.C.

INTRODUCTION

To assist in focussing upon the nature of contaminants and their effects upon organisms of the Fraser River estuary, it is important to recognize the uses to which this part of the aquatic system is subjected: notwithstanding the activities and their "effects" in upstream regions.

The 1400 km Fraser River drains an area of 233,100 km². It is in the lower Fraser Valley, close to the river mouth that most development has taken place. About 1.6 million people lived in this area in 1976 and it is forecast that the population will grow by a factor of about 2.2 over the next 40 years. Much of this development is to occur in areas peripheral to the main population centre encompassed by the Greater Vancouver Regional District (G.V.R.D.). Before Land Use Control legislation (1974), about 1400 hectares were developed annually for urban and industrial uses: uses which place a demand on the aquatic system, particularly to receive and accommodate waste products.

Agricultural activities utilize about 190×10^3 hectares, of which 35×10^3 hectares are used for animal husbandry. But, it is in the regions proximal to the river mouth, along the Fraser River estuary seawards of New Westminster, that industrial and urban growth has primarily occurred.

Contaminant Sources

Pesticides

Little information is available on the quantities of pesticides used in the lower Fraser River and estuarine area. While more than 400 permits a

year are given for applications in B.C., the use of such compounds on private land (e.g. agricultural property) remains uncertain. More than 100 pesticides are registered for use under provincial legislation and many are toxic to aquatic organisms. For example, 'Dinoseb' is applied in the Fraser Valley, to potato crops in particular. In B.C., about 30×10^3 kg are used annually representing about 25% of the national demand. As silvicultural requirements increase, so could the use of particular "conifer-release" herbicides and possibly some insecticides. Lumber treatment facilities, many of which are adjacent to the Fraser River estuary, utilize large quantities of chlorinated phenolics (about 680×10^3 kg per annum in B.C.). Creosote is also used (about 3.9×10^6 kg per annum in B.C.) and together these wood preservatives pose a significant threat to aquatic resources. It is not surprising, therefore, that Environment Canada has placed a high priority upon the management of wood preservatives. A decision which was based upon potential hazard (toxicity, bioaccumulation potential, environmental persistence and exposure potential). Even under conditions of maximum dilution in the Fraser River, we have recorded elevated levels of pentachlorophenol in the North Arm waters.

Landfills

Eight major landfills are located adjacent to the lower Fraser River and estuary. They result in the direct and indirect discharge of $> 7.5 \times 10^6$ L·d⁻¹ of organic contaminants, ammonia and solids. According to J. Atwater (Civil Engineering Department, University of British Columbia) there is no present method for predicting what concentrations of leached contaminants can be expected at any given time.

Stormwater

Within the G.V.R.D. 100 separate stormwater discharges and 12 combined sewer overflows discharge to the lower Fraser River and estuary. Stormwater is the source of many contaminants (oil, grease, phenols, pesticides, PCBs, metals). Furthermore, it has been estimated that 50% of effluents entering the lower Fraser River are of stormwater.

Industrial Effluent

The lower Fraser River and estuary receive discharges from about 108 outfalls (municipal 23, cooling water 21, forest products 24, food processing 14, metal processing 9, cement production 7, miscellaneous 10). The average discharge is about $330 \times 10^3 \text{ m}^3 \cdot \text{d}^{-1}$ of which 51% enters the North Arm of the Fraser River which carries only 10 - 15% of the total river flow. The main or South Arm of the river receives about 32% of the industrial effluent, while reaches above the South Arm-North Arm flow split (New Westminster) receive about 17%. At times of low river flow (February, March and early April), which typically also coincides with wet weather in the lower B.C. mainland, adverse river dilution conditions exist and it is possible that significantly greater than 5% of water in the North Arm of the Fraser River could be of industrial origin.

Municipal Effluent

Upstream of the G.V.R.D., within the lower Fraser Valley (regions of Hope, Kent-Agassiz, Langley, Chilliwack, Mission, Abbotsford, Matsqui and Harrison) municipal effluent receives secondary treatment, and is discharged to the Fraser River at an average flow of about $40 \times 10^3 \text{ m}^3 \cdot \text{d}^{-1}$.

Within the G.V.R.D. area, about $700 \times 10^3 \text{ m}^3 \cdot \text{d}^{-1}$ of mainly primary treated wastes are discharged into the estuary of the Fraser River. This represents a significant effluent flow which varies noticeably with climatic (rainfall) conditions. For example, the minimum flow of effluent at the Iona Island sewage treatment plant may be about $2.5 \text{ m}^3 \cdot \text{s}^{-1}$, but the maximum flow would be $17.7 \text{ m}^3 \cdot \text{s}^{-1}$ (equivalent to that from about 9 pulp mills) with the average flow about $4.7 \text{ m}^3 \cdot \text{s}^{-1}$. The Iona Island sewage treatment plant receives about 7% industrial waste and discharges at the upper intertidal zone of the extensive sandflats of Sturgeon Banks. This area is highly utilized by rearing salmon and other organisms. Regular fish kills (often daily, and by tide) here have been recorded during spring and summer in the area receiving the wastes. It is, however, from the Annacis Island sewage treatment plant that much of the industrial wastes are discharged. Maximum effluent flows from this treatment facility should be realized within 40 years, with flows of $6.8 \text{ m}^3 \cdot \text{s}^{-1}$, and the industrial component now comprises >35% of the total discharge volume. Of this, oil refineries, a hardboard plant, paper plant, wire, steelpipe and metal plating facilities, a chemical plant and 3 landfills are the major contributors. There is basically little control over substances entering the plant, which provides primary treatment, chlorination and dechlorination, prior to discharge.

Aquatic Contaminants and Organisms

Effluent Dilution and Dispersion

By reference to just one of the many effluent (contaminant) sources in the estuary of the Fraser, it is possible to exemplify the concern for the health of aquatic organisms and their environment.

Concern exists over the toxicity of the effluent from the Annacis Island sewage treatment plant, the level of treatment, lethal and sublethal effects (bioaccumulation, stress, disease, behavioural changes, etc.) in relation to prevailing conditions in the estuary.

The effluent is discharged into the tidal South Arm of the Fraser River below New Westminster. Slack tide conditions may persist for 5-6 hours, on occasions, with a maximum monthly total of about 50 hours. Between February and May 1980, 213 h of slack tide conditions existed in the Fraser River by this outfall. This occurred at the time of downstream juvenile salmon migrations. At slack tide, it has been predicted that effluent pooling and spreading across the river will occur within 2 hours. Subsequent dilution may be 15:1 2.4 km downstream on the next ebb tide. Furthermore, during dye studies to examine dispersion, a 3:1 dilution was recorded at the outfall site at a third of the usual effluent flow, and "multiple dosing" of water bodies with this acutely toxic effluent will occur under certain low river flows and tidal amplitudes.

Exposure of Organisms

If we just consider juvenile salmon and eulachon, and not the countless other organisms (resident and transient), it is apparent that at times of low effluent dilution numerous individuals will encounter decreased water quality conditions in the vicinity of the Annacis Island outfall, and similarly in other areas of the tidal portion of the Fraser River estuary. Based upon an assumption that about 600 million juvenile salmon will migrate seawards in the later winter and spring (February to June) and 10 million adult eulachon will migrate upstream within this period to spawn in the lower Fraser Valley and produce about 6 billion larvae, the following approximate exposures may occur to dilutions of acutely toxic Annacis Island

sewage treatment effluent. Based upon the occurrence of slack tide conditions alone, and ignoring the probability of multiple dosing of water masses at low flow periods, and recognizing the general surface water orientation of juvenile salmon in estuaries and nearshore coastal waters: about 44 million juvenile salmon would be exposed to reduced water quality conditions and 300 million eulachon larvae.

We currently have no information on the effects, nor their significance, to the individuals and populations, of such exposures to this and many other effluents, singly or in combination.

From an examination of average effluent and stormwater flows, it is apparent that a significant portion of wastewaters entering the estuary of the Fraser River carry many contaminants. Dilution of these wastes under low river flow and wet weather conditions could be of the order of 5:1, and at the critical salmon downstream migration period.

Many organisms are considered to be resident within the Fraser River estuary and lower reaches of the river. Evidence of contaminant accumulation has been shown in some of these species (squawfish, sculpins, starry flounders). Apart from our own research (Salmon Habitat Section of the Fisheries Research Branch, Department of Fisheries and Oceans) on the effects of municipal waste from the Iona Island sewage treatment plant on juvenile chinook salmon, there has been little coordinated research on the effects of contaminants on organisms of the Fraser River estuary. Similarly, much of the monitoring which has occurred has been fragmentary. Such work has, however, revealed that there are locations in the estuary, particularly in the North Arm of the Fraser River and on Sturgeon Bank, where contaminants have been accumulated by aquatic organisms. The topic of contaminant build up and effects on organisms begs to be addressed. The aquatic resources of the Fraser River are unique and extremely valuable.

Their health, and that of their environment, will only be assured through well conceived multidisciplinary research aimed at understanding the effects of contaminants on individuals and populations (stocks).

Questions to Consider:

During this session on contaminants and aquatic organisms, it will be important to focus attention on a number of issues. Accordingly, I have submitted a number of questions that, hopefully, we could address.

1. What are the objectives of a toxic chemicals research program? Why are we carrying out this work? We must not lose sight of the objectives of the research. Monitoring chemicals and their metabolites must be linked to research on their effects in the system, for it is the health of the environment and populations using it which requires preservation.
2. What criteria will be, or are, used upon which decisions are made to permit, restrict or refuse the disposal of toxic chemicals directly or indirectly to aquatic systems?

We need to determine what type of information is required and how we will use it for decision making. For example: Is the loss of a species (stock) an appropriate criterion? Reference to the loss of then-harvested salmon in the Thames River was obviously not an appropriate criterion in the late 1800s nor the massive deterioration in this aquatic environment in the mid-1900s. Preventative action, based upon sound scientific data, will go far towards offsetting future, often extremely alarming and expensive remedial measures caused by poor criteria setting, and a lack of awareness of basic ecological

and toxicological processes.

3. What should we examine, how, when and where? Should we examine effluents research effects of single compounds in the laboratory and the field?
4. What should a research program include in light of the continually changing dynamic estuarine environment? Successional changes will occur, hence the temporal aspects of change must be recognized and addressed.
5. How do we examine toxic chemicals in the stratified estuarine environment? What information is required in relation to such marked changes in the physical and chemical environment (sediment/water fluxes, etc.).
6. Is the quality and quantity of biological knowledge on organisms of the Fraser River estuary adequate to assist in toxic chemicals research? Do we know enough about the exposure of organisms to contaminants, habitats used, behaviour and other aspects of survival and mortality?
7. Is the presence of an organism a good indicator of environmental health? Some tubificids may be present in both relatively 'clean' and also highly organically polluted environments and accordingly "presence" per se would not be a good criterion. Similarly, live organisms may not reflect their internal health; they may appear healthy, but, in reality, are diseased.
8. Should single species be examined in toxic chemicals research or ecosystems? What are the merits and disadvantages?
9. To what extent should the health of organisms (of, for example, resident or transient fish species) be examined in relation to toxic chemicals? We always seem to sample the living portion of

a population of organisms; How do we address the concern that a fraction of the population may have already succumbed to the contaminant(s)?

10. To what extent does an organism or system accommodate toxic compounds without 'harm'? What are the protective mechanisms involved and what are the consequences of such physiological/biochemical reactions to the well-being of the organism?
11. How applicable are current techniques for examining the productivity and health of aquatic systems?
12. Can field research and laboratory research be carried out independently while attempting to understand "processes"? What is the best balance of effort and what components (disciplines) should be coordinated?
13. Can we adequately assess the exposure of organisms, both sessile and motile, in the estuary of the Fraser River with our current knowledge? How do we examine residency of organisms and relate this to exposure to contaminants?
14. Should population 'success' of organisms be an assessment 'tool' recognizing that individuals comprise populations (and stocks)? Is our understanding of a stock thorough enough to relate to the effects of contaminants?
15. Statistical validation - is it important? If so, how do we carry out research in the estuarine environment and produce 'meaningful' results that will be isolated from 'natural' variability?
16. Faced with a multitude of contaminants from 'point' and 'diffuse' sources in the Fraser River estuary, how do we effectively research toxic chemicals and their effects?

The questions listed above are only some of those which need to be

considered during the workshop. The fundamental question of primary focus is however:

17. What are the priorities for toxic chemicals research in the estuary of the Fraser River?

WORKSHOP DISCUSSION

The session on "Effects on Biota" focused primarily on the question "What are priorities for toxic chemicals research in the Fraser estuary?" Workshop participants spent the morning session in a general discussion, then during the afternoon session they hastily compiled a summary research agenda to examine the effects of toxic chemicals on biota in the lower Fraser River (Table 1.). This table summarizes the discussion points and accordingly is not comprehensive; caution should be used in its interpretation. There was a consensus that the main priority is to provide a healthy environment and thereby ensure the health and perpetuation of aquatic communities.

During the workshop, several topics were raised, including which toxicants to study, what approach should be taken in research studies, what species are most important to protect, and what key studies on individual species should be conducted. Time constraints did not allow full discussion of these topics, especially regarding key studies to perform on interrelationships between food web organisms and how contaminants affect these relationships.

There was a consensus that chlorinated phenolics (e.g. pentachlorophenol) and metals are priority toxicological problems. However, Dr. Jeff Thompson (I.O.S.) questioned the accuracy of present data on levels of metals, and of lead in particular. He stressed the need to know the

chemistry of metals in the estuary, their speciation (free ionic vs. complexed forms), and effects of salinity on speciation. Dr. Peter Oloffs (S.F.U.) stated that the only question of interest regarding DDT, DDE and chlordane is what the "picture" is today versus ten years ago and that monitoring of levels should not be continued. However, Dr. Ross Norstrom (C.W.S.) opposed this view and said that samples of pesticides and PCBs are inexpensive; therefore, monitoring should continue to determine long term trends.

The discussion on what approach to take in research studies focused on the "health" of the river versus the health of salmon species, components of the ecosystem versus the ecosystem as a whole, the development of LD50-type versus sublethal standards and the need for studies on behaviour, the value of field in situ versus laboratory studies, effects of toxicants on particular species and habitats, and synergistic effects of toxicants (e.g. in sewage effluents). It was concluded that both the overall "health" of the river and the health of species (particularly salmon) were priorities for research. The health of the river could be monitored using indicator species, but there was debate on the merits of using particular species for this purpose (see below). Dr. Ian Birtwell (D.F.O.) expressed his view that we cannot continue testing the effects of all contaminants on individual species, and there was consensus on his point that we should look at the ecosystem as a whole, as well as effects on key components of the ecosystem (in addition to salmon). It was recognized that an examination of all components of the ecosystem would be an extraordinarily complex task and that funding will certainly not be adequate to do all studies. Dr. Oloffs suggested that we should give "worst case" studies priority (e.g. chlorophenols or sewage at high concentrations), especially at Annacis Island Sewage Treatment Plant, and determine the relevance or importance of

the contamination problem to the ecosystem (e.g. what probability is there that a certain proportion of a particular salmon population will be affected?).

There was debate on the value of different types of toxicity standards to develop. Although most standards have been reported as LD50's, their value was questioned due to the frequent lack of proper reporting (e.g. confidence limits) and the fact that they ignore sublethal effects and ignore concentrations that kill less than 50% of organisms. Dr. Tom Northcote (U.B.C.) emphasized the critical need for information on the behaviour of juvenile and returning adult salmon. For example, a large number of juvenile chinook salmon from the Harrison River system choose habitats in sidechannels and are faithful to one particular channel for several weeks. Contamination of sidechannels may seriously impact particular salmon stocks. Predator avoidance (e.g. dart swimming speed), growth and behavioural avoidance of contaminants are important sublethal effects that are indicators of survival that LD50-type (acute toxicity) bioassays do not provide. Dr. Paul Harrison (U.B.C.) stressed the importance of field tests and in situ techniques for the assessment of sublethal effects. He recommended that a large (e.g. several acres) pen be constructed near Annacis Island to assess effects of sewage effluent, and recognized that smaller cages often have limitations for this purpose due to stress to test organisms from water flow and sedimentation. Although there was a consensus that field experiments are often superior to laboratory tests, Dr. Northcote indicated that large pens may cause problems in survival and alter behaviour and species interactions of fish that are not critical aspects of survival in the wild (e.g. escape from predators).

There was agreement that salmon species, particularly those that are known to be declining (e.g. chinook salmon) are priority species to protect.

There was also a consensus that the protection of resident coarse fish species and herons should be a priority.

The main points from the discussion on what key studies on individual species should be conducted is summarized in Table 1. The discussion centred on the value of particular species as indicators to the "health" of the river (e.g. plants and invertebrates, food web relationships, as well as other species that are important to protect (e.g. fish and birds). There was a consensus that, if possible, indicator species should be sessile, thereby integrating conditions at one location of the river, and that they be part of the food chain of fish and bird predators. Dr. Ian Hutchinson (S.F.U.) recommended emergent macrophytes as an indicator plant, especially the sedge grass Carex spp., but pointed out the need for a euryhaline plant due to the varying salinity along the course of the river estuary, and the need to standardize the degree of submergence and dessication. The value of using plants as indicators was questioned due to their lack of bioaccumulation and metal-binding proteins. However, Scirpus spp. has been used as an indicator for its accumulation of phenolics, and Fucus spp. accumulate contaminants in its mucous material. Enteromorpha spp. was also recommended. Although crabs were recommended as indicators, the mobility of adults reduced their value to indicate the level of contamination in discrete locations. Crab larvae may be useful indicators due to their sensitivity to contaminants. There was a consensus on the point raised by Dr. Jim Servizi (I.P.S.F.C.) and Dr. Ken Lum (N.W.R.I.) that one indicator species or test will not be adequate to monitor the "health" of the river, but rather a series of tests using more than one indicator species should be developed. There was debate on whether studies on fish should focus on salmon or resident coarse fish species. Although our immediate priority is to protect salmon species, they may be differentially affected by

contaminants compared to coarse fish. Salmon are known to survive short-term "lethal" barriers, but although salmon residency in the estuary is extremely brief compared with that of coarse fish species, even brief exposure to "extreme" rather than "average" toxicant concentrations may have detrimental effects. The "detoxification" mechanisms of salmon (e.g. metal-binding proteins) are relatively ineffective compared with those of coarse fish species. Salmon avoid some toxicants and potentially lethal effluents, but may be attracted to others which, for example, could be present in the Annacis Island sewage treatment plant effluent (Dr. Birtwell). On the other hand, coarse fish species (e.g. flounder, carp and sculpin) that are resident in the river may be more vulnerable to toxicants due to both short and prolonged exposure. Although salmon are presently more economically important than coarse fish, within the next hundred years we may harvest coarse fish for human consumption. Therefore, it is important to protect these species and their environment now. Some coarse fish (e.g. carp) are already being harvested, although this is not a large fishery. There was agreement that toxicological studies should focus on both salmon and coarse fish species. Dr. Servizi stated that there is very little known about the effect of contaminants on the number of adult salmon returning to the river, particularly on chinook, chum, and coho salmon. Coarse fish species that should be studied include starry flounder and sculpin. Starry flounder is in the food chain of herons. Sculpin apparently have a relatively high rate of uptake of contaminants, and there is a high correlation between the rate of uptake and the concentration of the contaminants in the water (Lee Harding, E.P.S.).

Great blue heron (GBH) and snow geese were suggested for research on birds species. However, since GBH are resident in four colonies in the lower Fraser River area and snow geese are transient, GBH may be more

vulnerable to effects of toxicants than snow geese, and also more useful for monitoring over time. It was agreed that since the U.B.C. colony of GBH has a higher concentration of contaminants (e.g. chlorinated compounds) than the other colonies in the area, studies and protection efforts should be directed mainly at the U.B.C. colony.

It was concluded that research on the effects of toxic chemicals on biota must be interdisciplinary studies, and research groups must be cooperative in their efforts to meet their overall objective of the provision of a healthy environment for the aquatic community in the lower Fraser River.

TABLE 1. SUMMARY OF RESEARCH PRIORITIES TO DETERMINE THE EFFECTS OF TOXIC CHEMICALS ON BIOTA IN THE LOWER FRASER RIVER.¹

SPECIES	T E S T S		
	HABITAT	FIELD	LABORATORY
<u>Plants:</u>			
<u>Carex sp.</u>	extensive distribution	(relate to exposure time and control for genotype) - Metals Cd, Cu, Zn, Pb, Fe, Hg	- physiological effects of metals
<u>Enteromorpha sp.</u>	sloughs	- populations - metals as above	- biochemistry, kinetics - induction - protective mechanisms - life history, reproduction
<u>Invertebrates:</u>			
<u>Oligochaetes</u>	Rare in Fraser River estuary may be good indicator organisms		
<u>Leeches</u>	river, sloughs, banks	- Metals Cd, Cu, Zn, Pb, Sn, Hg	- as above
<u>Gammarids</u>	outer and inner estuary	- metals as above, especially in hepatopancreas - PAHS - organochlorines (trace and ultratrace) - pathological examination - residency relative to exposure	- effects on physiology - biochemistry - induction of protective mechanisms (eg. metal-binding proteins) - pathological examination
<u>Crab adults and larvae</u>			
<u>Molluscs (Macoma, Mytilus)</u>	(incomplete due to time limitations)		

TABLE 1. SUMMARY OF RESEARCH PRIORITIES TO DETERMINE THE EFFECTS OF TOXIC CHEMICALS ON BIOTA IN THE LOWER FRASER RIVER.¹

SPECIES	T E S T S		
	HABITATA	FIELD	LABORATORY
<u>Fish:</u> Chinook salmon parramolds or juveniles (age 0 ⁺) N.B. wild vs. artificially reared	sloughs, banks, (outer estuary) migration pathways, lower river marshes migration and residence near Annacis	- chronic exposure, eg. <u>Annacis</u> to metals and organochlorines - in situ bioassays - stress, blood chemistry, oemoregulation, histopathology - corals - resident time - metals - acute lethality and sublethal effects	- chronic exposure to: - metals - organics - organophosphates chlorinated organics - sublethal effects of metals, organochlorines on: - stress - swimming, eg. dart speed - behavioural changes that affect survival (preference, avoidance; - predator - prey interactions) - protective mechanisms - pathological examination - as above for juveniles - as above for chinook juveniles
Chinook salmon adults Flounders Sculpine?	migration pathways river, banks	- population or stock assessment - pathological examination - metals - organics	

TABLE 1. SUMMARY OF RESEARCH PRIORITIES TO DETERMINE THE EFFECTS OF TOXIC CHEMICALS ON BIOTA IN THE LOWER FRASER RIVER.¹

SPECIES	T E S T S	
	HABITAT	FIELD LABORATORY
<u>Birds:</u> Herons	four colonies, concentrate study on UBC colony	- population ecology, residency - feeding ecology - organics - eggs - contaminants - (trace, ultratrace), methyl-Hg - bioaccumulation of metals

¹Note that items are not prioritized.

SESSION V

WATER QUALITY OBJECTIVES - AQUATIC ENVIRONMENTAL QUALITY REQUIREMENTS

Facilitator: Diana Valiela, Inland Waters Directorate

Rapporteur: E. Ann Gallie, Department of Zoology, U.B.C.

INTRODUCTION

Water quality objectives (W.Q.O's) have been suggested as one of a variety of management tools that may be useful for the Fraser estuary. A number of definitions may be used for W.Q.O's (see following workshop discussion for one working definition); most include the notion that W.Q.O's are levels, concentrations, or other characteristics of water, sediment, or biota, which, if complied with, will not cause specified negative effects on water uses (including fish and other aquatic life) at a specific location. Water quality objectives are useful as a management tool for a number of reasons. They can serve as a basis for issuing waste control permits; they are an aid to land use planning; they can provide a foundation for agreement on acceptable water quality; and they can help to assess the performance of water quality management efforts. W.Q.O's also aid information transfer and acquisition: they provide scientific information in a form usable by managers and the public; also, the process of formulation of W.Q.O's aids in understanding the system and in defining data gaps and their importance.

Formulation of W.Q.O's for the Fraser estuary is a complicated undertaking. There is a variety of water uses; a great diversity of habitats (geographically and temporally highly variable flow regimes, depths, salinity/tidal fluxes, substrates); a large number and variety of point and non-point sources of pollution; and great diversity of marine, estuarine, and freshwater biota whose estuarine biology is relatively poorly known. Water uses in the Fraser estuary include fish and aquatic life, including a number of commercially important species; recreation, primarily

but not exclusively non-contact; and a myriad of industrial and irrigation uses, some of which are currently not well-described. A systematic examination of these uses and of existing water quality data would allow a preliminary identification of the toxic chemicals and associated variables of concern for formulating W.Q.O's.

Following identification of variables of concern, W.Q.O's for those variables can be formulated using a combination of two general approaches. In one approach, existing criteria (information on the effects expected for different levels of exposure to the toxic chemical or other variable in question) can be adjusted or modified for the site in question by considering the expected form(s) of the compound, the species or life stage present, the environmental conditions (temperature, pH, salinity, etc.), and the existing or "background" levels of the toxic chemical. This approach is difficult to apply in the case of the Fraser estuary because the site-specific conditions differ markedly from those of most literature criteria information. An alternative approach, the derivation of new site-specific criteria (experimentally derived for the species and conditions in question in the system itself or its simulations) will have to be applied very selectively because of the expense and time required to perform such duties.

This workshop session will attempt to identify and prioritize information and research needs to develop W.Q.O's for the Fraser estuary. This will include identification of water uses for which W.Q.Os will be developed; toxic chemicals of concern for W.Q.O's; formulation of W.Q.O's; baseline data needs; and compliance monitoring development.

WORKSHOP DISCUSSION

The workshop session began by defining "Water Quality Objectives (W.Q.O's)" and outlining steps usually taken in developing objectives. A W.Q.O. was defined as:

"A limit on or a level of a physical, chemical or biological characteristic of water, biota, or sediment, which if met will protect the designated water uses at a specific location with an adequate degree of safety, taking local circumstances into account."

This is one of a variety of definitions discussed in drafts of the Water Quality Objectives Division (Water Quality Branch, I.W.D., D.O.E.) Program Paper; it can serve as one working definition.

There was agreement that this adequately defined a W.Q.O., and that an objective so defined, on an ecosystem basis, was preferred to one based solely on chemical parameters of the water column.

Discussion on research needs was broken into subject areas. The major points made for each topic are summarized in the following, with the most important points listed first and indicated by an asterisk.

Rationale Behind the Development of W.Q.O's

*1. The group indicated that the philosophy behind the development and application of W.Q.O's needs to be explicitly described to improve their use as a management tool. Although the group recognized that the philosophical basis may vary between agencies or for different chemicals or ecosystem conditions, a clear understanding of how objectives will be applied is fundamental for both those developing and enforcing W.Q.O's and for those who must meet the objectives.

Although discussion of different philosophical approaches was limited, it was pointed out that both the "non-degradation" approach (as currently being applied in the Great Lakes) and the "assimilative capacity" approach have problems. For example, a non-degradation policy based on criteria at non-detectable levels may be difficult to interpret and apply as analytical methodologies continue to improve (i.e. improvement in detection limit). An approach based on setting allowable limits may encourage pollution to that limit; on the other hand, in already degraded situations an "assimilative capacity" approach may require improvement, while a non-degradation policy may not. Some support was expressed for an explicit combination of the two approaches.

2. Examples of the rationale behind the development and application of W.Q.O's in simpler aquatic systems than the Fraser estuary should be reviewed.

Water/Sediment Uses with Potential to be Affected by Water Quality

*1. Research is required on the use of the Fraser estuary by several species of fish or shellfish utilized for human consumption that may be affected by toxic chemicals, or that may be sources of toxic chemicals for humans. These include:

starry flounder
eulachon
longfin smelt
pacific smelt

Dungeness crab
carp
white sturgeon

Information needs include distribution in the estuary throughout the life cycle, population dynamics, community interactions, and food web components.

2. In addition to research on the basic biology of the species listed above, the nature and extent of specialized fisheries for these species should be investigated. The intent of these studies would be to outline "who is eating how much of what" and where are these fish taken.
3. Unlicensed water use for irrigation in the Fraser estuary is not well known. To understand what WQO's are required to protect this use, it is necessary to find out where water is being withdrawn, in what quantity and for what uses.
4. The extent and nature of recreational contact with Fraser estuary sediment should be investigated. Specifically, the use of dredged or other substrate material for beach fill, sand boxes, or other contact uses should be detailed.
5. A synthesis of published and unpublished literature on utilization of the Fraser estuary by aquatic birds should be prepared. The Canadian Wildlife Service (CWS) has information on which toxic chemicals are of most concern. By comparing maps of bird usage and distribution of chemicals, problem species and areas could be identified.
6. Research on use of the estuary and community characteristics of fish and other species not listed above (i.e. less well-known users) is also required.
7. Although it is assumed that toxic chemicals do not constrain industrial water use, the possibility of problems and their extent should be investigated.

Identification of Toxic Chemicals of Concern and their Sources

*1. Of prime importance to the development of W.Q.O's is the identification of a list of priority toxic chemicals of concern and their sources. Discussion on this topic was limited, however, because Workshop Session 1 was dealing specifically with the subject. Nevertheless, the following comments were made:

- o For fish and aquatic species, all trace metals and toxic organics are of concern.
- o For irrigation water, information is needed on which toxic chemicals are of concern. Asbestos fibers such as have been found in the Sumas River near Chilliwack were specifically mentioned as a major constraint to irrigation (and other water uses).
- o Toxic chemicals which concentrate in sediments and which can be absorbed through the skin are of concern for contact recreation. In addition, mercury (and other chemicals) which are volatile or can be absorbed if sand is eaten are of concern where estuary sand is used in children's playboxes.
- o Although impossible to specify, chemicals which in future may be of concern due to increased usage or potential toxicity should be investigated and monitored.

Fraser Estuary Water Quality Dynamics & Environmental
Information Needs

- *1. Greater understanding of bioavailability of metals and toxic organics is required. Specifically, research is needed on the chemical forms or species affecting bioavailability and transformation rates between these forms (e.g. methylation rates).
- *2. Research is needed on bioaccumulation of toxic chemicals at all levels of the ecosystem, and on the partitioning of chemicals among different tissues in fish and shellfish.
- *3. Detailed assessment of the exposure of selected salmonid juveniles to present levels of toxic chemicals is required. This work should focus on which chemicals are in fact present in high usage areas. Such data would feed into bioassay work on synergistic effects of toxic chemicals, discussed in the next section.
- 4. Related to bioavailability and bioaccumulation, studies are needed on uptake pathways, and chemical persistence and degradation, in the estuary.
- 5. In general, the transport and sedimentation of toxic chemicals within the estuary, and from upstream, needs to be better understood. Research needs were not discussed in detail as this is the subject of Workshop Session 2. Nevertheless, it was emphasized that knowledge of sediment dynamics, qualitative makeup, particle-size distribution and chemical sediment-water partitioning on a site-specific and seasonal basis is required as important input for W.Q.O's development.

6. Knowledge of dissolved oxygen (DO) concentrations and redox potential for the estuary is patchy. Especially in backwater or slough areas and in areas of effluent discharge, more thorough work is required. In these same locations, the effects of temperature and salinity on DO/redox potential should also be investigated.

7. Biological processes which may affect chemical concentration or sediment-chemical deposition rates should be investigated. Specifically, the distribution and abundance of macrophytes, and their role in removing toxic chemicals from the water column and in controlling sediment deposition, should be clarified.

Criteria for Development of W.Q.O's

*1. A detailed review of all existing information on toxicity effects and water quality criteria applicable to Fraser estuary species and chemicals of concern is required. Until this is complete, there was general agreement that a detailed needs list for research cannot be finalized.

*2. For criteria development, data is required on the lethal and sublethal effects of priority toxic chemicals on several aquatic species which are highly sensitive, use sloughs in the estuary where toxic chemicals may concentrate, and which are economically important. These include:

chinook salmon	)	
chum salmon	)	fry and smolts
sockeye salmon	)	
searun trout	)	

Dungeness crab)
longfin smelt) early life stages
pacific smelt)

starry flounder
eulachon
carp
white sturgeon

Toxicity effects should be investigated for a range of concentrations, and under different salinity, temperature and DO conditions such as are found in estuary backwaters.

*3. Similar studies to those described in the preceding point should be conducted using mixtures of chemicals to investigate the toxicology of synergistic effects. The group recognized the difficulty of such studies due to the large number of combinations possible. However, bioassays of mixtures as found in specific estuary locations were recommended as a good place to begin.

*4 Methods used to derive acceptable and sufficient water quality criteria and objectives from toxicology cause-effect data should be reviewed and described. In general, the group indicated that at present there are few formalized processes by which this is done, although the Delphi technique was suggested as one possible method for arriving at a consensus of opinion. Development of more objectives and scientific techniques for selecting appropriate criteria, clearly stating inherent assumptions, would be beneficial, but would have to depend on the rationale behind the W.Q.O's themselves.

*5 Research is required on how to adapt existing criteria developed for other species, chemicals or environmental conditions, when applicable toxicology cause-effect data is lacking. Specifically, work is needed on how and when extrapolation between aquatic species, chemicals or conditions is safe, and what confidence limits can be placed on the adapted criteria.

Compliance Monitoring

*1. The present arbitrary definition of dilution zones should be reviewed in context of the rationale behind W.Q.O's. The point of the review would be to define where W.Q.O's should and should not apply, recognizing site-specific mixing conditions.

*2. To determine areas for intensified monitoring on both a geographic and temporal basis, a series of map overlays should be prepared showing:

- temporal (seasonal or diel) and geographic distribution for key aquatic species.
- sources of pollution.
- distribution of water-sediment quality for priority toxic chemicals.

Such a task could be facilitated by creation of a central clearing house for Fraser estuary data, such as the one proposed for the Fraser River Estuary Management Program. The effectiveness of this approach, however, will depend on the extent to which researchers log their data into the geographic information system. (An additional benefit of such overlays would be to focus attention on geographic/temporal data gaps for specific aquatic species or environmental conditions.)

3. There is a need for development of new in-situ continuous monitoring methods, either in the form of automatic analytical machines or chemical-specific biomonitors. Such methods would allow much better definition of the variability of discharges and catch short-term peak discharges which other monitoring methods would miss.

4. The occurrence of abnormalities in key aquatic species should be mapped. This could form part of the Fraser estuary geographic information system and serve to identify priority monitoring sites.

CONCLUSIONS AND RECOMMENDATIONS

While time was limited, this first attempt to gather scientists together to exchange views on toxic chemicals in the lower Fraser River proved to be very productive. Even though the participants in the workshop were requested not to address topics such as quality control/quality assurance and analytical methodology due to time limitations, several sessions emphasized the necessity of a quality control/quality assurance program, development of suitable standard reference material and the standardization of analytical techniques. Many participants suggested that workshops of this kind should be held on a regular basis. Therefore, it is recommended that Environment Canada sponsor another workshop on the Fraser River estuary in 1987, and the workshop should include topics such as quality control/quality assurance and analytical methodology.

Little information is available on the variety of organic contaminants in the lower Fraser River system. This is particularly true in the case of agricultural pesticides. Even though Session I did not specifically address the question of agricultural pesticides as priority chemicals, it is widely recognized that some of these compounds being used in the lower Fraser River area should receive careful attention.

Several workshop sessions discussed the high cost of monitoring for organic contaminants, but no recommendations were proposed. It was suggested that targeting analytical techniques to specific compounds may reduce the cost of monitoring. However, such an approach aroused fears that some of the more toxic contaminants may not be identified. This problem is compounded by the fact that many of the toxic contaminants are sporadic in nature. A possible

way of dealing with these problems is to have the monitoring of specific organic contaminants supported by GC-MS scans on 24-hour composite samples periodically.

The workshop identified 45 topics where information is lacking for the management of toxic chemicals in the lower Fraser River. Some of these topics, such as pathogens and dissolved oxygen, are not strictly within the realm of "toxic chemicals". However, over 95% of the suggested research topics are related to toxic contaminants and many of these can be broken into several projects. In addition, most sessions emphasized the need for a multidisciplinary approach to research in the lower Fraser River. With the numerous information gaps identified for toxic chemicals in the Fraser River estuary, it is clear the problems are too great for any one organization to tackle alone. In this era of scarce resources, it is recommended that efforts be made to develop a cooperative program of coordinated research in the lower Fraser River irrespective of affiliation. Perhaps this initiative can be provided under the Fraser River Estuary Management Program.

Areas for research recommended by the various workshop sessions is listed on the following pages. The topics are not listed in order of priority.

1. monitor for trace organic contaminants from domestic sewers
2. for storm sewers -
 - (a) determine contaminant loading
 - (b) conduct pathogen inventory
 - (c) monitor for PAHs and conduct source inventory

3. for industrial effluents -
 - (a) review effluent permits with chemical inventory
 - (b) inventory of "solid" inputs from boat builders, bulk terminals, etc.
4. for drainage ditches -
 - (a) monitor agricultural pesticides
 - (b) monitor feed lot effluent and conduct inventory
 - (c) monitor trace organics in landfill leachates
5. determine atmospheric loadings
6. study ground water at sites such as Chatterton Chemicals
7. determine the mechanism and phase of transport, of the binding potential for toxic substances, and of the ultimate fate for the clay/silt fraction of the sediment
8. model the behaviour of major effluents
9. set guidelines to control the discharge of toxic chemicals to sewer systems
10. link sediment load measurements to flow observations wherever possible, and study the deposition of clay and silts in slack water areas

11. undertake an intensified program of current measurements in the trifurcation below New Westminster, at a variety of discharges and tidal conditions, to assess flow distribution in this area
12. determine the flow distribution in the Ladner area for a wide range of hydrodynamic conditions
13. estimate the overflow across Albion Dike during high discharges
14. research in hydrodynamics and sediment transport relating to toxic chemicals should be undertaken cooperatively with researchers in other disciplines such as chemistry and biology
15. characterize the seasonal aspect of suspended material and study their effect on sorption processes
16. determine the effect of precipitation of metal oxides on the partition of various chemicals in the system, particularly at the fresh/salt water interface
17. determine the physical state of inorganic contaminants at source, study their transportation and fate, and evaluate rates of sorption and desorption

18. evaluate the centrifuging technique as a method of sampling for suspended sediments for inorganic contaminants when high percentage of biomass is present and find an alternative technique, if necessary
19. determine the bioconcentration factors of the priority pollutants for species existent in the Fraser River estuary
20. standardize analytical techniques
21. develop standard reference material for contaminants in biota
22. conduct detailed fate studies using PCP and 2,3,4,6 TCP as models
23. relate transformation rates of other contaminants to PCP and 2,3,4,6 TCP using factors such as hydrolysis rate, biodegradation rate, volatilization rate and photodegradation rate
24. for plants (Carex sp. and Enteromorpha sp.)
 - (a) determine habitat and distribution
 - (b) monitor for trace metal concentration and relate to exposure time
 - (c) study physiological effects of metals

25. for invertebrates (oligochaetes, gammarida and crabs)
 - (a) study habitat and distribution
 - (b) monitor trace inorganic and organic contaminants and relate to exposure time
 - (c) conduct pathological examination where possible
 - (d) determine life history and reproduction
 - (e) determine the induction of protective mechanisms
 - (f) determine the physiological effects of trace contaminants
 - (g) study the biochemical effects of trace contaminants
26. for fish (salmonids, flounders, eulachon, smelt, carp and white sturgeon)
 - (a) study migration pathways and residence time where applicable
 - (b) determine habitat and distribution
 - (c) conduct in situ bioassays and laboratory studies to determine chronic exposure, acute lethality, stress, sublethal effects, avoidance levels, etc.
 - (d) monitor trace organic and inorganic pollutants
 - (e) conduct pathological examination
 - (f) conduct population studies as well as stock assessment
 - (g) study community interactions and food web components
 - (h) investigate nature and extent of fisheries for the species where applicable

27. for birds (great blue heron)
 - (a) study four colonies but concentrate on U.B.C. colony
 - (b) determine population ecology, residency and feeding ecology
 - (c) determine trace organic contaminants in eggs
 - (d) monitor the trace organic and inorganic contaminants in tissue where possible
28. determine the locations and quantities where water is being drawn for irrigation
29. determine the extent and nature of use of dredged sediments
30. compile information utilization of Fraser estuary by aquatic birds and compare distribution of toxic contaminants
31. research on use of estuary and community characteristics on species of fish not listed in 26
32. investigate the possibility of toxic chemicals creating problems for industrial use of water
33. study the bioavailability of trace metals in relation to chemical form or species
34. determine the uptake pathways of toxic organic and inorganic contaminants in biota

35. investigate the effect of temperatures and salinity on dissolved oxygen in sloughs and backwater areas
36. study biological processes which may affect chemical concentration or sediment deposition rates
37. review all existing information on toxicity effects and water quality criteria applicable to Fraser estuary species and contaminants of concern
38. investigate lethal and sublethal effects of priority toxic chemicals for fish species listed on 26
39. determine synergistic effects of the priority chemicals on applicable fish species wherever possible
40. develop an objective and scientific technique to derive acceptable and sufficient water criteria and objectives
41. develop procedure for adapting existing criteria for other species, chemicals or environmental conditions when applicable toxicological data is missing

42. review the definition of dilution zones in context of the rationale behind W.Q.O's
43. prepare a series of map overlays showing:
 - (a) temporal and geographical distribution of aquatic species
 - (b) pollutant sources
 - (c) distribution of water sediment quality for the priority chemicals
44. develop in situ automated continuous monitoring instruments where possible
45. map the occurrence of abnormalities in key aquatic species

It should be noted that no attempt was made to prioritize the topics in this summary. It is recognized that some of the recommendations, such as the preparation of maps, are not strictly "research" in nature, but are necessary components if a good understanding of the toxic chemicals in the Fraser is to be developed. It is hoped that the Research Institutes within government, universities and regional personnel will coordinate their efforts to develop a 'research agenda' based on the recommendations in this report.

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